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Ecosystem Services Research Program (ESRP)

Decision Support Framework (DSF) Team
Research Implementation Plan

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1. Introduction

In 2000, an EPA Science Advisory Board (SAB) published a report entitled "Toward Integrated Environmental Decision-Making" (U.S. Environmental Protection Agency 2000) and pointed to EPA's outstanding need "to assess cumulative, aggregate risks; to consider a broader range of options for managing or preventing risks; to make clear the role of societal (public) values in deciding what to protect; to clarify the trade-offs (including costs and benefits) associated with choosing some management scenarios and not others; and to evaluate progress toward desired environmental outcomes". The SAB suggested a Framework for Integrated Environmental Decision-Making (see Figure 1) that "adopts an interdisciplinary approach that combines deep understanding of environmental science with theory and empirical methods in behavioral and decision science".

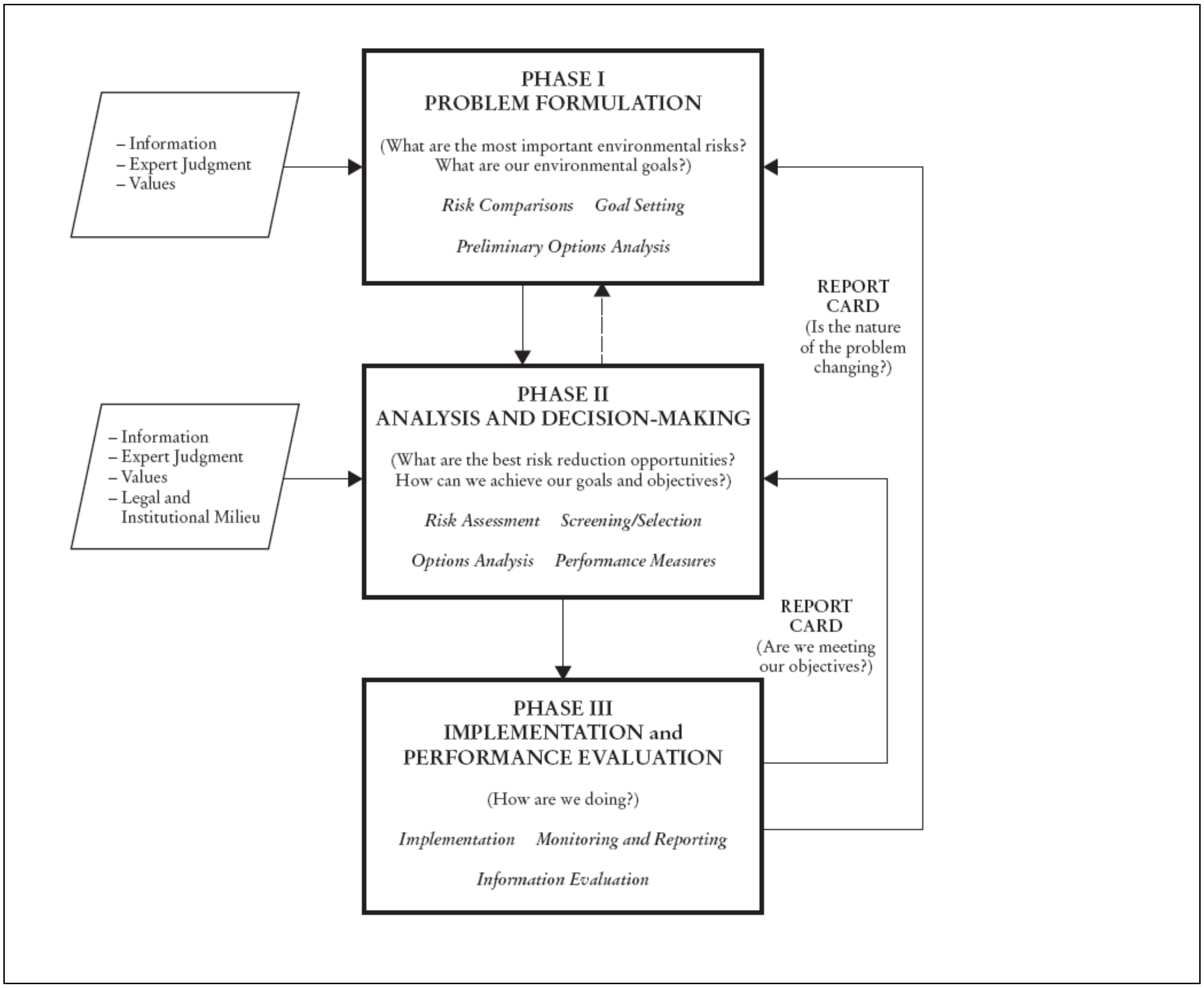


Figure 1: Framework for Integrated Environmental Decision-making (U.S. Environmental Protection Agency 2000)

In its 2000 report the SAB asked EPA to begin to make major changes to the way the Agency framed and addressed environmental problems. However, they pointed out that this new decision-making framework would build upon several previous efforts. These include the risk assessment/risk management model described by the National Research Council (National Research Council 1983), the update to that report (National Research Council 1994), the ecological risk assessment framework (U.S. Environmental Protection Agency 1982), the report of the Presidential/Congressional Commission on Risk Assessment/Risk Management (United States 1997) (see also Figure 2) and the risk characterization process described by the NRC (National Research Council 1996), which focused on the interaction between analytic and deliberative processes in decision-making.

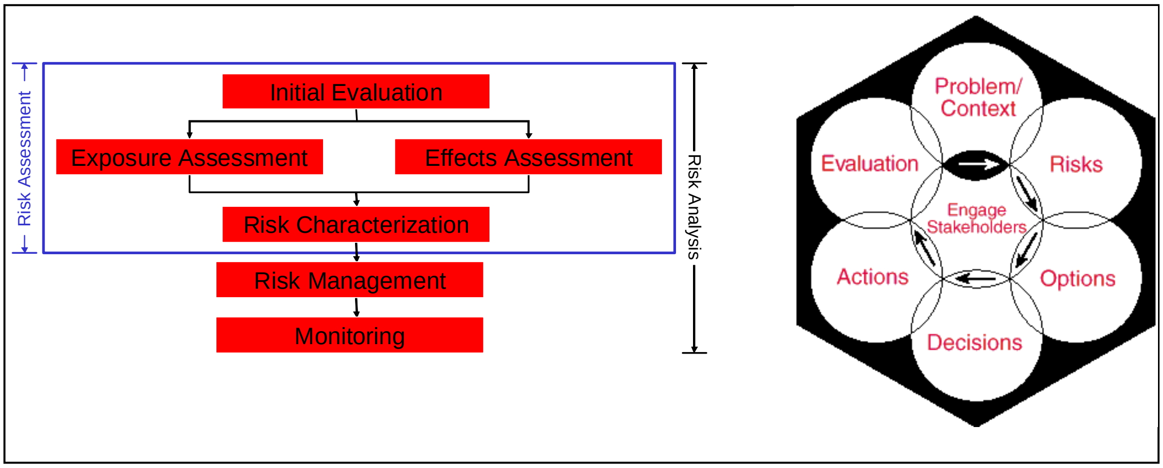


Figure 2: The logical model for EPA's analysis and management of risk continues to evolve. Left panel: Initial models were largely designed around single pollutant – single exposure pathways. Risk assessments and much of the risk analyses were conducted by scientists. Although effective for the purpose for which it was designed, this framework was less effective for assessment and analysis of risk in more complex problems. Right panel: The 1997 Presidential/Congressional panel proposed a systematic, comprehensive framework that can address various contaminants, media, and sources of exposure, as well as public values, perceptions, and ethics, and that keeps the focus on the risk management goal (United States 1997).

In 2003 the U.S. Environmental Protection Agency (EPA) and the National Science Foundation (NSF) requested the National Research Council (NRC) to help set research priorities for the social and behavioral sciences as these relate to several different kinds of environmental problems. Their specific task was to identify a manageable number of promising research questions, the answers to which were believed to contribute to improved environmental decision making. In the report "Decision Making for the Environment: Social and Behavioral Science Research Priorities" (National Research Council 2005), the authors recommended 5 science priorities.

- Federal agencies should support a program of research in the decision sciences addressed to improving the analytical tools and deliberative processes necessary for good environmental decision making.
- Federal scientific and environmental agencies should support a concerted effort to build scientific understanding needed for designing and evaluating institutions for governing human activities that affect environmental resources.
- Federal agencies should substantially expand support for research to understand the influence of environmental considerations in business decisions.

- Federal agencies should support a concerted research effort to better understand and inform environmentally significant decisions by individuals.
- To strengthen the scientific infrastructure for evidence-based environmental policy, the federal government should pursue a research strategy that emphasizes decision relevance.

The first priority of the 2005 NRC report is the DSF team's first priority and we quote its recommendations in this paragraph. Good environmental decision making requires not only good environmental science, but also improved understanding of human-environment interactions and development and implementation of decision-making processes. These processes must integrate scientific understanding with deliberative processes to ensure that the science is judged to be decision relevant and credible by the range of parties interested in or affected by the decisions. Three needs were identified to achieve this goal.

- Developing criteria of decision quality. Research is needed to define decision quality for practical environmental decisions. It would consider such questions as: Which characteristics of decision processes are associated with judgments of decision quality or acceptability by decision participants and observers? Do different groups of decision-makers and stakeholders apply different criteria of decision quality? To what extent does increased attention to ideals of good public decision processes yield more positive assessments of actual decision quality? Are decisions of higher normative quality associated with preferred social and environmental outcomes? How can research results on such questions best be disseminated to their potential users?

- Developing and testing formal tools for structuring decision processes. Research is needed to refine and apply tools from the decision sciences for helping decision-makers better approximate ideals of good decision processes. The research might address such questions as: How can formal methods of value elicitation be applied effectively in real world decision settings? How can judgments about the nature and likelihood of a range of outcomes be made more routine and workable through the use of information technologies? What systematic methods for arriving at collective preference can be applied in realistic environmental decision settings that can complement those of social benefit-cost analysis and that do not adopt problematic assumptions typical of that approach? How can learning be built into decision procedures to allow for updating over time? How can risk communication methods be used to make issues of preference and uncertainty intelligible and useful to key decision-makers and affected parties? How can decision-aiding approaches help individuals by structuring the values, uncertainties, and broader implications of their choices?

- Creating effective analytic-deliberative processes. Research is needed to strengthen the scientific base for organizing processes, such as are now being used with increasing frequency in government, in which a broad range of participants take important roles in environmental decisions, including framing and interpreting scientific analyses. The recommended research would address such questions as: What are good indicators for key attributes of success for analytic-deliberative processes, such as decision quality, legitimacy, and improved capacity for future decision making? How are these outcomes affected by the ways the processes are organized, the ways they incorporate technical information, and the environmental, social, organizational, and legal contexts of the decision at hand? How can decision processes be organized to ensure that all sources of relevant information, including the local knowledge claims of nonscientists, are gathered and appropriately considered? How can these processes be organized to reach closure, given the challenges of diverse participants and perspectives? How can decision-analytic techniques be used to improve these decision processes? How can technical analyses be made transparent to decision participants who lack technical training?

With this assessment of the evolution of the guidance ORD has received and continues to receive from external advisory panels, the ESRP Decision Support Framework (DSF) team is developing an implementation strategy. The DSF team, in developing this implementation plan, recognizes the current lack of Agency knowledge about environmental decision-making processes and decision science, and the limited resources currently available to develop this capability within the ESRP, ORD and the Agency. The plan results from the selection of key goals and a realistic assessment of what is currently possible within the context of the ESRP. This plan is designed to allow the DSF team to adapt to new knowledge, resources and acceptance of an evolving environmental management mandate for the Agency.

2. Strategic Overview

The ESRP DSF team has determined, after over a year of preliminary information gathering, that it needs to continue learning about analytic-deliberation processes (including participatory decision making and decision analysis) and collecting and organizing existing data and information. The DSF team has also determined, based on the results of two workshops (Coastal Carolinas and Coral Reefs – more information in Sections 3.2 and 3.4), literature reviews, and discussions with ESRP project leads that our decision support efforts need to focus on the ecosystem services impacts of land and resource use decisions.

2.1. Decision-Makers

Figure 3 depicts one of the major technical challenges faced by the DSF team, that of scale. Land and resource use decisions are typically made by individuals, towns, counties, tribes, states and sometimes multiple states (regions) to increase economic viability of an area. However, decision-makers frequently fail to consider or weigh the long term effects on human health and the environment in local-regional decision-making processes. Improved decision-making includes awareness of the cumulative (and incremental) impacts of multiple local decisions (bottom-up) and the local consequences and opportunities of regional/national environmental policy (top-down). Individuals and groups who typically make land and resource use decisions do not all currently have the capability to evaluate the impact that their decisions have on ecosystem services and socio-cultural needs. The ESRP DSF will improve this capability.

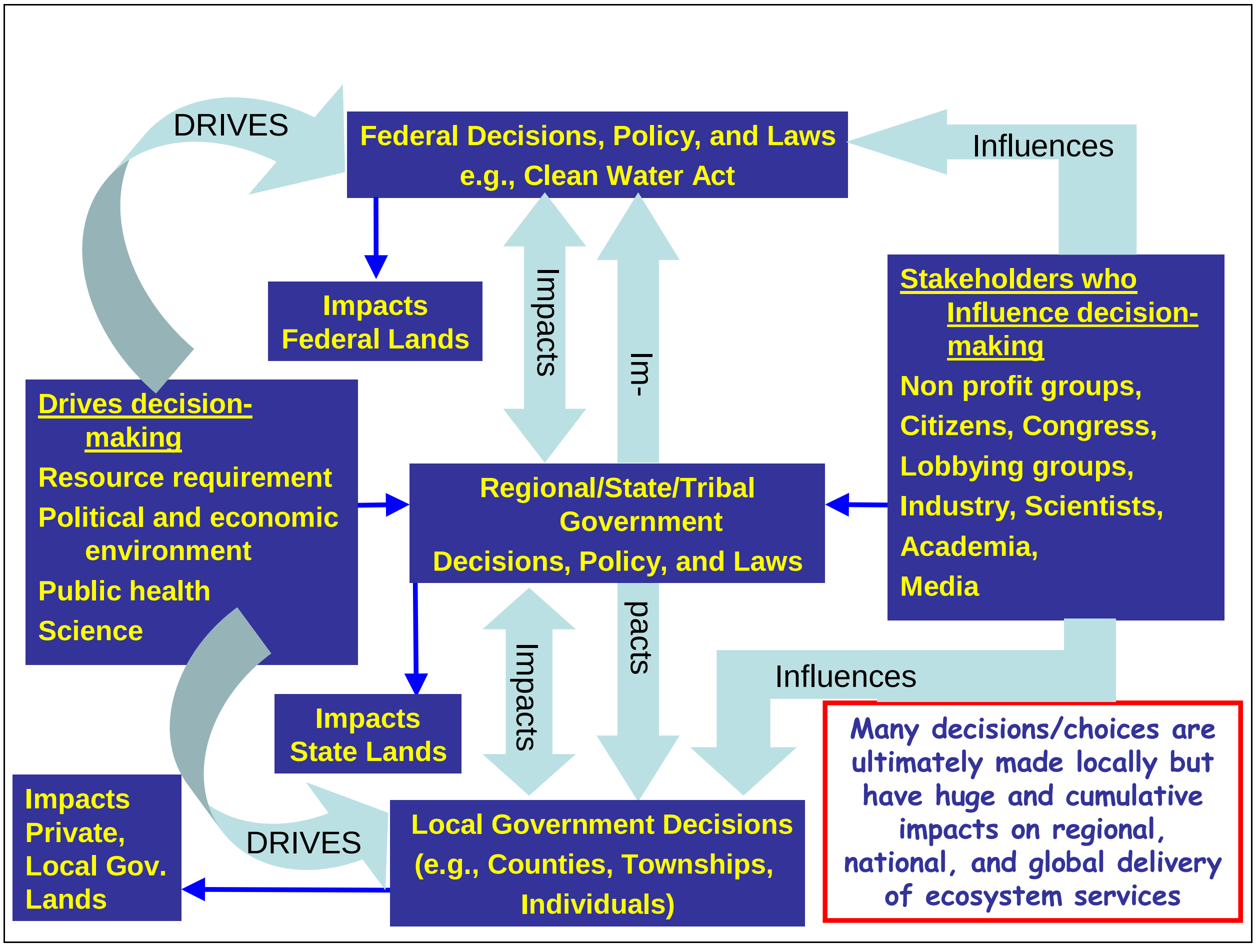


Figure 3: Decision Making Occurs at Multiple Levels

2.2. EPA Authority

EPA lacks strong and explicit regulatory authority to protect ecosystem services. The majority of lands and almost all freshwater wetlands in the US are private property. Given this, what mechanisms does EPA possess or can develop to influence environmental decisions and their impact on ecosystem services? Salzman (2007) provided a perspective on this issue which the DSF workgroup used to help define the research goal in terms of what the DSF should be and how it should be used:

- Penalties - Up to now a major mechanism has been for the EPA to prescribe environmental regulations and penalize those who are proven to be noncompliant to the regulations.
- Property rights - Some land rights are viewed as property (e.g., mineral rights) and are marketed. Environmental land rights might also be classified as property and made marketable.
- Payments - Payment for services rendered could result in payments to farmers for removing reactive nitrogen in wetland riparian zones before the field runoff enters streams.

- Persuasion - In many cases persuasion may be the most effective. If people are aware of consequences to environmental services many will make environmental management decisions that will minimize impacts. This is particularly true when financial advantages revealed by life cycle analyses are made apparent.

All these mechanisms are important and their application depends on the context of the specific problem. A successful DSF will help clarify which mechanisms are most appropriate for a specific problem and enhance the effectiveness of any chosen mechanism.

2.3. Vision and Goal

Vision: To create a flexible yet robust framework of knowledge and information that decision-makers can use to help structure environmentally-impacting decision processes. These processes will enable stakeholders to identify and understand relevant technical information and balance the value of ecosystem services with economic and social values in a transparent way. We will initially focus on providing decision-makers with an understanding of the implications of land and resource use alternatives. This understanding will enable decision-makers to make decisions consistent with present and future desires of the community while maintaining and sustaining functional natural systems and the services they provide.

Goal: By 2016, the Decision Support Framework (DSF) team will provide an analytic-deliberative DSF for land and resource use decision-makers at the local, state, tribal and regional scales.

The ESRP DSF is a structured decision analysis framework with associated tools that will enable land and resource use decision-makers to make better informed decisions incorporating ecosystem services and desired environmental quality. The DSF will provide decision-makers an understanding of probable effects of their planned decisions on social, economic and ecological systems - thus enabling our planet to sustain society and nature.

Supported decisions include environmental stressors and land use choices of national significance such as: pollutant discharges, the built environment, agriculture, transportation, and energy use on local, state/tribal, and regional scales.

3. Phase 1 – Lessons Learned by Doing

The following subsections provide a chronology of events occurring in Year 1 of DSF team activities, including the changes made to the direction of the DSF team as a result of lessons learned.

3.1. Rationale for a Framework (not a Platform)

In spring/summer 2008, the ESRP Multi-Year Plan (MYP) was reviewed by the Science Advisory Board (SAB). The draft SAB report then underwent a quality review in fall of

2008. One of the SAB quality reviewers had grave concerns with the plans for the decision support platform (DSP) as described in the MYP. This reviewer took issue with the development of an on-line system that would integrate the tools and models from the other ESRP teams without first understanding what decision-makers and stakeholders needed and wanted. The DSP team re-wrote the draft implementation plan to address these concerns and the draft implementation plan was sent out for review in the winter of 2008.

In January 2009, after attending a joint Outreach and Education (OE)/Coastal Carolinas workshop, the DSP team determined that an on-line platform that fully integrated all products from the other ESRP teams was not necessarily what decision-makers needed or wanted. The team was renamed the Decision Support Framework (DSF) team to reflect the change in focus from an on-line platform to collecting information and understanding what decision-makers and stakeholders needed/wanted.

Since fall of 2008, the DSF team has begun focusing more on what decision-makers and stakeholders need to facilitate decisions related to land and resource use. Ecosystem services are NOT routinely considered in such decisions and this reduces the chances of their protection. Decisions are being made without:

- identifying and including stakeholders impacted by the decision
- understanding stakeholder and decision-maker values and preferences
- fully examining the problem
- creating goals and objectives for the desired outcomes
- determining attributes to measure effectiveness of how well an alternative meets an objective
- investigating insights needed to create multiple alternatives that can be evaluated with respect to the objectives
- understanding potential impacts and the tradeoffs that need to be made, and
- understanding the uncertainties of predictions.

Basically, decisions are being made outside of a structured decision analysis framework and therefore decisions aren’t including many of the important elements needed to make an informed decision (Gregory and Keeney 2002; Reckhow 2003).

The DSF team has therefore selected behavioral decision research and decision analysis to form the basis of the DSF described above. We have renamed the team and refocused our efforts on the development of a decision support *framework* to emphasize this shift in thought. In this implementation plan, the DSF team has also addressed SAB comments, SAB quality reviewer comments, and comments received on the draft implementation plan. Direct responses to the SAB comments can be found in Appendix 1.

3.2. Lessons Learned from OE/Coastal Carolinas Workshop

In January 2009, several members of the DSF team participated in an OE/Coastal Carolinas workshop. The summary below was produced from a series of public meetings in Charleston, Litchfield and Bluffton, South Carolina. The following excerpt is quoted from the unpublished summary:

"The most prominent concern, nearly universally expressed, is the broad spectrum of adverse effects resulting from rapid, inadequately planned and regulated, ecologically disharmonious anthropogenic development.

Based on a combination of the participants' emphasis and frequency of mention, these specific issues emerged as the most prominent, significant or urgent:

- Uncontrolled, poorly planned and ecologically inappropriate anthropogenic (human) development degrades and threatens a broad spectrum of environmental quality, and quality of life values.
- Inadequate policy, regulatory and enforcement mechanisms fail to prevent or constrain inappropriate development, or provide incentives for low impact development. By law, if a permit application meets established guidelines the permit must be issued. Additional impacts, such as loss of ecosystem services, are not established criteria for consideration.
- Degradation of water quality (e.g., fecal coliforms, eutrophication, lowered dissolved oxygen, sedimentation/turbidity, pharmaceuticals, metals, invasive species) impacts aquatic habitats and commercial and recreational fishing.
- Aesthetics have deteriorated.
- Terrestrial and aquatic wildlife habitat is no longer healthy due to loss, fragmentation, and impairment.
- The overall ecosystem functioning and health has degraded.
- Residents have lost their intrinsic 'sense of place'."

The conceptual model (see Section 3.3) was developed in response to what was learned during these public meetings.

3.3. Conceptual Model

The DSF team developed a conceptual model in March 2009 based on literature reviews and preliminary information received from other ESRP teams. The conceptual model is depicted in Figure 4.

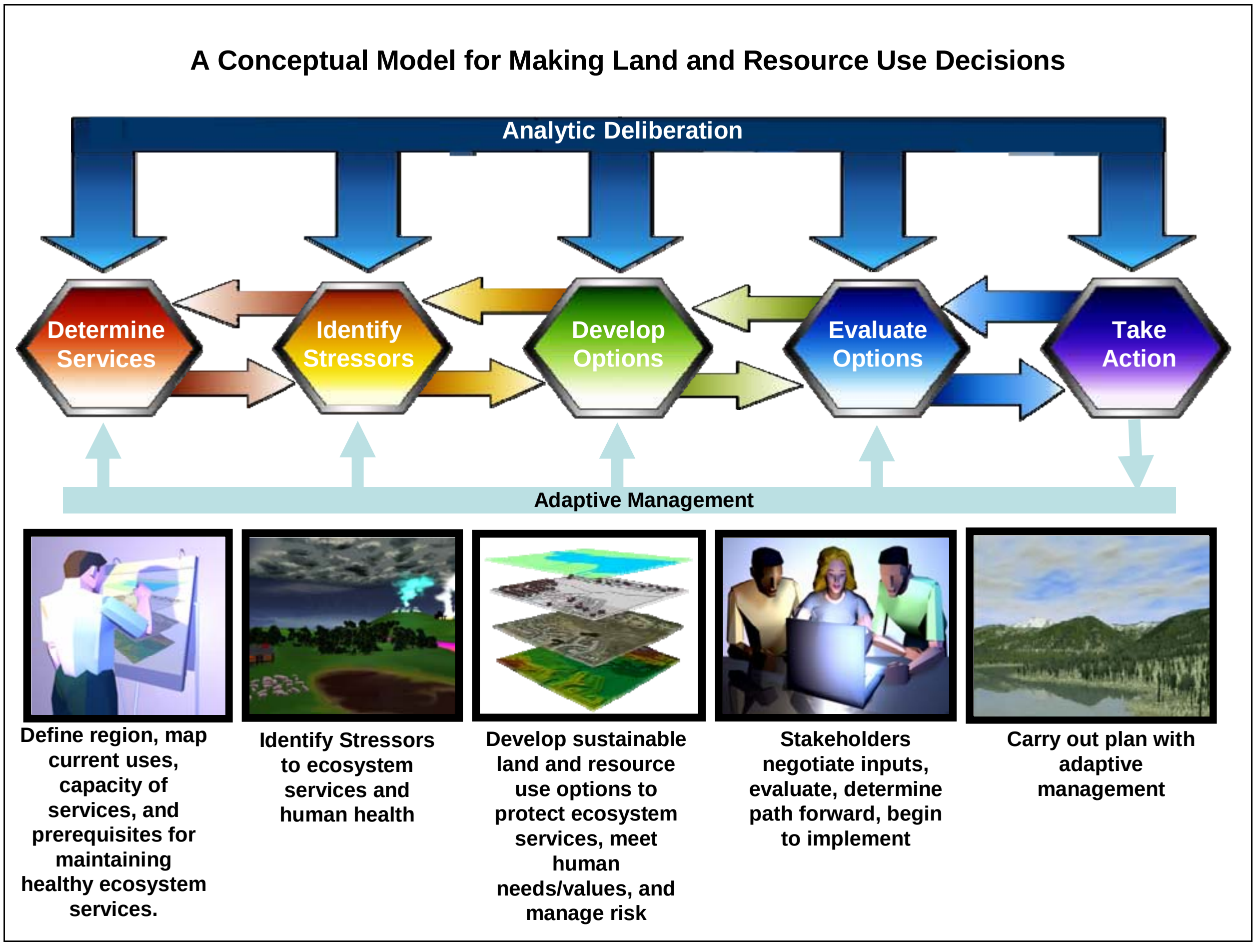


Figure 4: Conceptual Model for Making Land and Resource Use Decisions

The draft conceptual model for the DSF has now evolved into a schematic of the DSF (see Section 4.1), but the five modules and two overarching themes in Figure 4 are still represented in the schematic:

- Determine Services (define area of interest, services of interest, condition/status and carrying capacity of services of interest, current land and resource use, etc.)
- Identify Stressors (including type, magnitude, spatial and temporal effects of stressor/driver)
- Develop Options (create desirable, feasible, and realizable land and resource use options to protect ecosystem services, meet human needs, and manage risk; use scientific data, computer based models, values of stakeholders, etc.)
- Evaluate Options (stakeholders use agreed-upon measurement rules to score options; consider uncertainty, value of collecting additional information; evaluate tradeoffs, risks, opportunities, consequences)
- Take Action (determine next steps and implement them; revisit periodically and adapt as needed).

In each process module, all of the most appropriate technical information must be understood by stakeholders and decision-makers and environmental values weighed against economic and social values in a participatory analytic-deliberative process. Once a decision is implemented, adaptive management requires periodic evaluation of the results of the action and, as warranted, a determination of whether or not changes in data, models, or ecosystem conditions demonstrate the need for revisiting any steps in the decision-making process.

3.3.1. Analytic-Deliberation

The ESRP Decision Support Framework will be used to encourage decision-makers to incorporate scientific information about ecosystem services into their planned land and resource use decisions. A component in development of the DSF will be the use of analytic-deliberation. Analytic-deliberation can best be described as a structured discussion among scientists, decision-makers, and parties with an interest in a policy or decision. The goals of the discussion are to define the problem, to identify the values and outcomes of concern, to distinguish disagreements that must be addressed through compromise and tradeoff from those that might be resolved with better information, and to agree on appropriate ways to collect and interpret the needed information. Analytic-deliberation emphasizes people's ability to process language and develop mutual understanding (Dietz 1994; Renn 1999; 2001; 2006).

While analysis uses rigorous, scientific methods to obtain factual information, the focus of deliberation is on discussion, reflection, and striving to understand other points of view (National Research Council 1996). Figure 5 illustrates use of analytic-deliberation in a risk decision process.

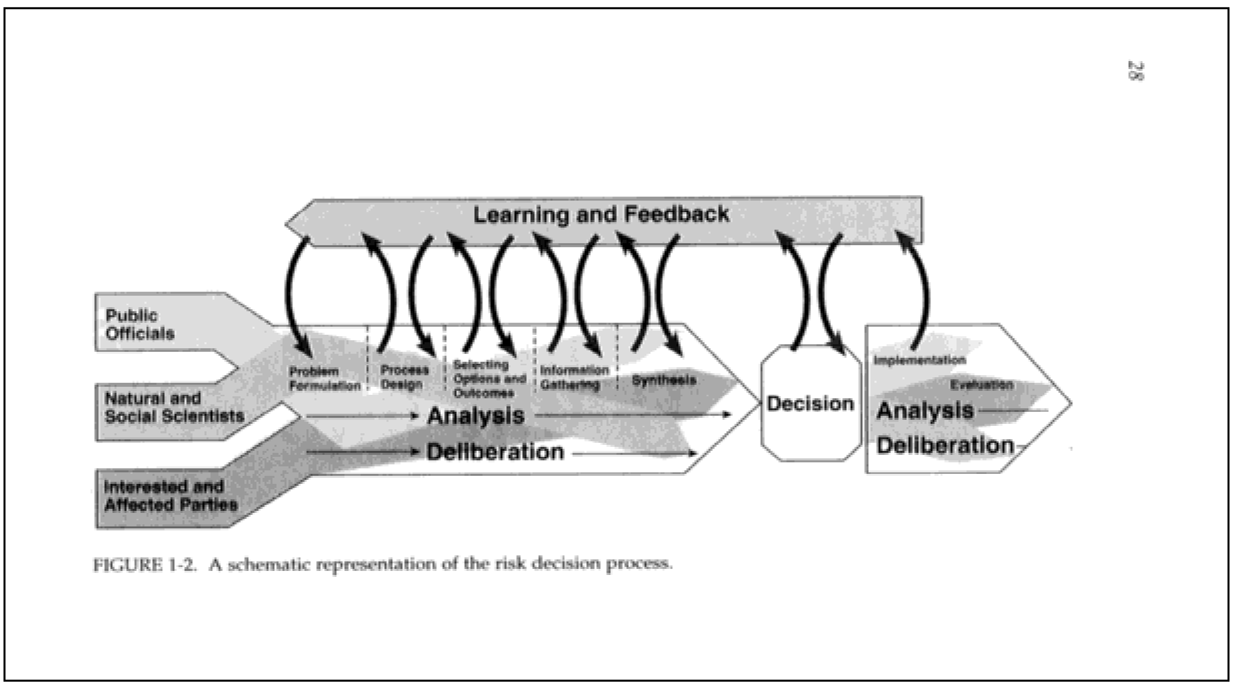


Figure 5: Analytic-Deliberation as presented in a risk decision process. (National Research Council 1996).

3.3.2. Adaptive Management

Adaptive management is a strategy for managing environmental systems with highly uncertain responses to alternative actions by monitoring, interpreting, and using these responses to adjust policies in an iterative manner, providing ongoing improvements in knowledge and resource productivity (Holling 1978; Lee 1999; National Research Council 2003; Walters 1986; 1997; Walters and Holling 1990). As noted by Lee (1999), “adaptive management is learning while doing; it does not postpone action until ‘enough’ is known but acknowledges that time and resources are too short to defer some action.” As such, adaptive management provides a structured approach for making decisions in the face of uncertainty and seeking to improve these decisions by actively acquiring the knowledge necessary to reduce the uncertainty. Adaptive management is also enhanced by formal analysis and optimization methods, e.g., (Williams 2001) and by broad stakeholder participation (Schindler and Cheek 1999), as illustrated by the DSF conceptual model (see Figure 4).

Adaptive management has been applied primarily to wildlife and ecosystem management (see, for example, its incorporation into the U.S. Forest Service’s Land and Resources Management Plans (U.S. Forest Service 2009), decisions by the Alaska Department of Fish and Game (Alaska Department of Fish & Game 2001) and the EPA/Environment Canada-sponsored Lake Superior Lakewide Management Plan (U.S. Environmental Protection Agency 2006)). An NRC review of the adaptive management program for ecosystem resources in the Grand Canyon (National Research Council 1999) suggests the application of (Ojeda-Martinez et al.) a long-term monitoring program and (2) a strategy for scientific evaluation of policy alternatives in terms of ecological and stakeholder valuation outcomes. The authors note that an effective adaptive management program will require tradeoffs among objectives preferred by different stakeholders and methods for fairly weighting these objectives. Similarly, an NRC report (National Research Council 2002) supports using adaptive management to advance scientific inquiry and policy formulation for the Missouri River ecosystem. The authors suggest an approach that includes (Ojeda-Martinez et al.) programs to maintain and restore ecosystem resilience; (2) recognizing and adapting to uncertainty; (3) interdisciplinary collaboration; (4) models to support collaboration and decisions; (5) meaningful representation of a wide array of interest groups; and (6) ecosystem monitoring to evaluate the impacts of management actions. Adaptive management is also applied outside of the US (e.g., (McClanahan et al. 2006; Mostert et al. 2007; Olsson et al. 2004; Wells 2006).

3.4. Lessons Learned from DSF/Coral Reefs Workshop

After development of the initial conceptual model, the DSF and Coral Reefs teams organized a joint workshop in June 2009, Key West, FL at the Florida Keys National Marine Sanctuary. The workshop goals were to:

- Explore a collaborative vision among decision-makers, scientists and other coral reef stakeholders for sustainable coral reefs
- Initiate a systematic, deliberative process to analyze coastal and watershed decisions that impact coral reefs
- Advance an integrative framework to incorporate the ecological, social, economic and legal consequences of alternative decisions.

A major focus of the workshop was the Drivers, Pressures, States, Impacts, Response (DPSIR) Framework. The DPSIR Framework characterizes causal relationships among categories labeled as Driving forces, Pressures, State, Impact and Response (Pierce 1998; Smeets and Weterings 1999). This model was adopted by the European Environmental Agency and has been used by the United Nations to organize information about the state of the environment in relation to human activities (UNEP 2007). Examples of DPSIR in use include a decision support system for evaluation of wetland ecosystem management (Turner et al. 2000) and evaluation of ecosystem-based management alternatives for Marine Protected Areas (Ojeda-Martinez et al. 2009). Figure 6 provides a visual of the DPSIR Framework. DPSIR definitions are:

- **D**riving forces: Socio-economic sectors that describe basic needs of human society such as food, water, fuel and shelter, and secondary needs such as recreation, cultural heritage and sense of place
- **P**ressures: Driver-related human activities that affect the environment
- **S**tate: status of the environment and ecological resources, including attributes that provide services; state is altered by changes in pressure
- **I**mpacts: changes in coral reef condition, persistence and delivery of services as a consequence of changes in ecological state; changes can be valued
- **R**esponse: societal reactions to changes in ecosystem services, values and sustainability

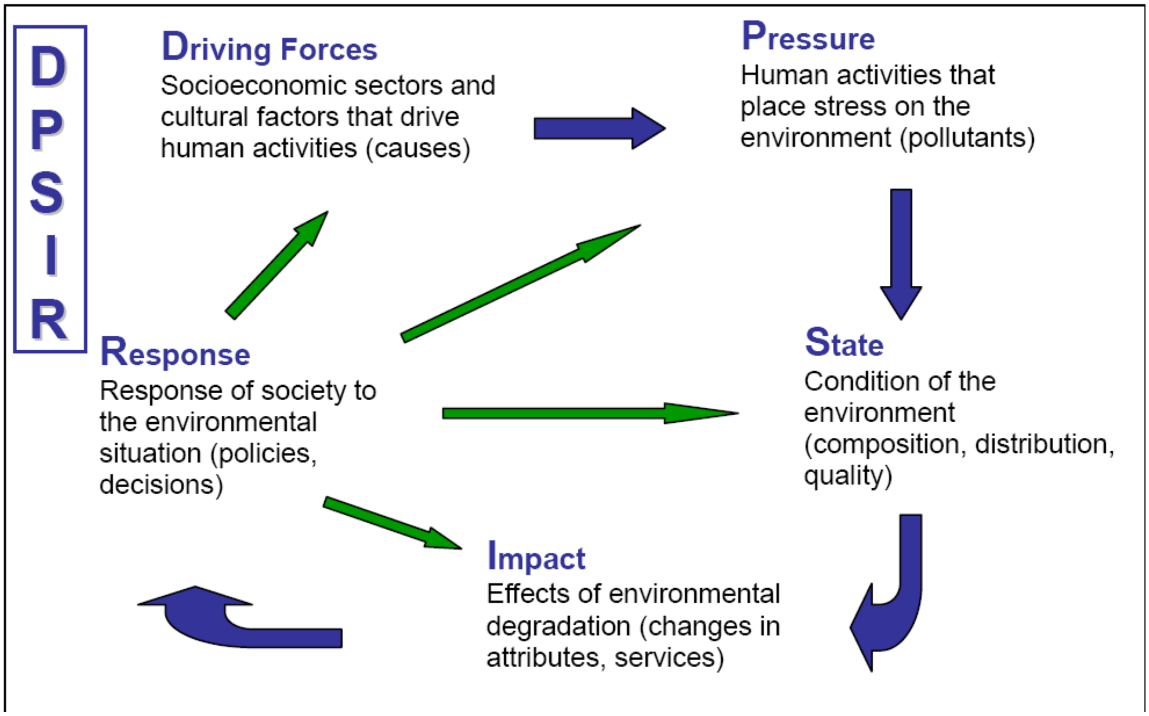


Figure 6: Conceptual relationships among DPSIR sectors.

The workshop provided a significant amount of information for both the Coral Reefs team and the DSF team. Based on a compilation of notes during discussions and small group sessions, the following key points relative to the DSF team were made:

- A holistic, integrated decision-making framework is needed for the entire reef ecosystem (not just stony corals) and everything that impacts that ecosystem (e.g., land use). Impacts from a larger region, including 25 coastal states, Mississippi River, and the Everglades, need to be incorporated into the big picture. Once documented, research and resources need to be coordinated to focus on addressing problems within the holistic plan. In other words, we must determine needs first, and then collect the right data.
- Public support for coral protection is mixed. This is due to mixed messages being sent by scientific papers, the media, and a general lack of a comprehensive understanding of the issues. It is important for the public to believe in science and management solutions. The public wants scientific integrity. It is important to include the public in all steps of the decision process so they have direct access to information and can ask questions to enhance their understanding.
- Confidence in data for management decisions needs to be considered. In some cases, a high level of accuracy is needed, but in other cases, not as much. It is necessary to balance resources and additional research with the level of accuracy needed.
- Both management-based science and science-based management are needed. In other words, scientists need to understand what decisions managers need to make, and do the research that informs those decisions. Likewise, managers need to communicate with scientists about what research is needed to address a problem. Scientists and managers must work together continuously.

- There is a perception that much of the research has been completed, and no decisions have been made. Decisions need to be made often with incomplete data. An approach is needed to address this perception of lack of action.
- We need to focus on benefits and not just costs of environmental protection. The DPSIR framework can help with this.
- We must be proactive in addition to reactive. We must work to prevent problems from happening in the first place.
- The public needs to be better educated with the right information. Common misperceptions need to be addressed. The complexity and interrelationship of things need to be communicated and understood.
- Decision science/analysis is needed.

The DSF team began to consider how to evolve the conceptual model into a decision support framework (DSF) that would address many of the needs/issues identified in the OE/Coastal Carolinas workshop and the DSF/Coral Reefs workshop. The first lesson learned is that we are still in a very formative phase of the DSF research. New knowledge gained still has relatively large impacts on the direction and implementation of the DSF effort. On the other hand the DSF team realized that many of the needs/issues could be extrapolated beyond these two specific projects so that the eventual DSF could be applied more broadly. The approach we are taking is adaptive.

4. Phase 2 – Current Approach

4.1. Evolution of a DSF Schematic

A draft schematic of a DSF for supporting land and resource use decisions is provided below.

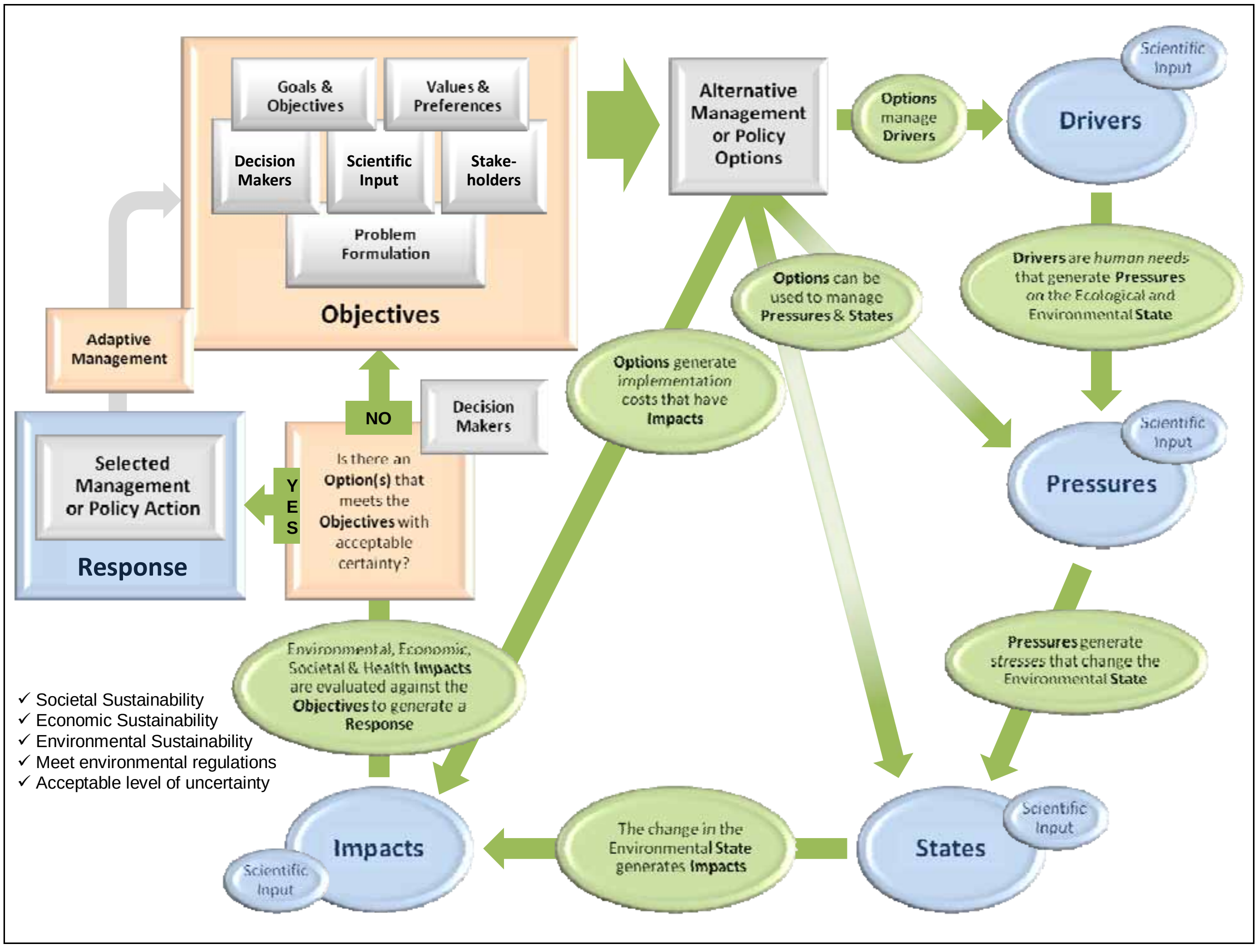


Figure 7: Draft DSF Schematic

This draft schematic combines a decision analysis framework (generally following the decision analysis steps in (Reckhow 2003)) with the DPSIR framework (UNEP/GRID-Arendal 2002). In the Figure, we start with the "Objectives" box. This is where the decision problem and decision landscape (context) are defined. Because of the importance of this piece, additional discussion is provided in Appendix 2.

To develop objectives, one must first define the problem. This includes identifying decision-makers, stakeholders and groups/individuals affected by the decision. Problem formulation results from an iterative and deliberative process involving stakeholders and decision-makers. The stakeholders and decision-makers work to establish:

- A clear understanding of the problem and its context(s) including spatial and temporal scales
- Goals and objectives for each decision-maker/stakeholder group
- Values and preferences for each decision-maker/stakeholder group.

Once the problem is well formulated and bounded, decision consequences are discussed leading to the identification of objectives and attributes (measureable endpoints). The decision problem is then structured to enhance communication among decision-maker/stakeholder groups.

Management and/or policy options are developed in order to address the problem. The DPSIR framework is used to organize the quantitative evaluation of the consequences of options with respect to the objectives and attributes, ecosystem services in particular. Models, maps, monitoring data and other tools are used to do the evaluation itself.

Finally – the decision-makers determine the action they wish to take (response).

A hypothetical example of how the framework could be used to inform a wastewater-related decision can be found in Appendix 3. This is a very simplistic example intended only to illustrate how decision analysis and the DPSIR framework can be used to address a specific problem.

By 2016, we envision a comprehensive, systems level framework that will allow decision-makers and stakeholders to evaluate planned land and resource use management options to determine their impacts on ecological sustainability (using bundled ecosystem services and production functions), social sustainability (including human well-being, quality of life and sense of place), and economic sustainability.

A list of sustainable land use planning criteria (compiled by an EPA community planner) will be used, in addition to objectives, values, and preferences, to inform land and resource use management options as part of the evaluation. A description of the planning criteria is provided in Appendix 4.

4.2. Application of DSF Schematic for Additional Development

During 1970-2005, approximately 53% of the nation's population lived in coastal areas of the U.S. (http://www.census.gov/Press-Release/www/emergencies/coast_areas.html). NOAA's National Ocean Service study of growth in coastal counties (Crossett et al. 2004) and the Millennium Ecosystem Assessment Report both project increasing development and stress on coastal ecosystems, which are among the most productive yet highly threatened systems in the world (Dayton et al. 2005). Population densities in U.S. coastal areas are triple those in non-coastal areas (mean 305 vs. 57, median 104 vs. 36, respectively: http://www.census.gov/Press-Release/www/emergencies/coast_areas.html). Economic interests and needs for housing, water, and transportation exacerbate stresses on the coastal ecosystem from habitat loss, excess nutrients, invasive species, contamination, and climate change. The ESRP matrix of stressor, habitat, and place is structured to allow in-depth, targeted research to be extrapolated to additional stressors, habitats, and places. Similarly, the development and application of our DSF requires pilot projects that target decision-making venues and scales where stakes are high, possible returns are large, and study questions can be clearly defined. Together, the Coral Reefs and the Coastal Carolina projects meet these needs, and also allow us to take advantage of pre-existing interagency and NGO collaborations.

The DSF team, in conjunction with the Coral Reefs and Coastal Carolinas teams (including stakeholders and decision-makers), will use the schematic above (Figure 7) to evolve a land and resource use decision support framework (DSF) to support land and resource use decisions. Working with Coral Reef and Coastal Carolinas' decision-makers and stakeholders, the DSF team will develop and apply a framework that enables identification of all the elements needed to evaluate multiple land and resource use options for a defined area. The Coral Reefs and Coastal Carolinas teams (with the assistance of the Nitrogen, Wetlands, Mapping, Monitoring, Modeling, and Human Well-Being teams) will bring together (and often develop) the data, information and models necessary to allow decision-makers and stakeholders to evaluate those land and resource use options. In other words, the DSF team will develop and apply the framework while the data and models needed to use the framework will be developed by other ESRP teams. Representatives from all of the above mentioned teams will participate in the development, application, and use of the DSF.

The focus on Coral Reefs and Coastal Carolinas will enable us to support decision-makers who are in immediate, critical need of support. Resource constraints (both human and financial) only allow us to work with two teams in this phase. Additionally, the Coral Reefs and Coastal Carolinas projects are in the early stages of research, making it an ideal time for us to begin collaboration.

As noted above, members of the ESRP theme projects (mapping, monitoring, modeling, outreach and education, valuation, and human-well being) are also embedded in both the Coral Reefs and Coastal Carolinas projects. Wetlands and Nitrogen issues are a primary focus in the Coastal Carolinas project.

4.3. Importance of Continuous Involvement with Stakeholders and Decision-makers

In keeping with the newly coined principle of "pervasive responsibility", every member of the ESRP and every partner and client is part of the process of designing, developing, and implementing the ESRP DSF. We plan to update the familiar phrase: "If you build it, they will come" and operate under the motto "***If you invite them to build it with you, they're already there.***"

This means that DSF team members become members of the other ESRP place-based projects, ecosystem based projects and pollutant based project. This enables ongoing interactions with stakeholders and decision-makers to obtain their perspectives, guidance, and partnership in the design, development and implementation of the ESRP DSF.

If we do our work well, ESRP products will support national, regional and local efforts to create a sustainable balance of growth and development with protection and conservation so the needs of people and nature can be realized. Yet this will not be easy for reasons beyond the scientific challenge. While it is important to develop the science that allows us to better understand how human activities and behaviors deplete or preserve earth's natural capital, knowledge alone does not translate into action. We must tailor our products and share scientific results in a form that activates behavioral change. To accomplish this we must understand and influence the types, diversity, and context of relevant decisions being made, the perspectives of the stakeholders/decision-makers, their conceptual understanding of ecosystem services, and their motivations in the decision process that would enhance the acceptance and use of ecosystem services and human well-being in the decisions they make. Scientific understanding, public will, and community action combined offer decision-makers the tools for protecting and enhancing ecosystem services and thus help ensure their integrity and productivity in the face of ever increasing human pressures.

Due to reasons listed above, the DSF team will be imbedded initially in two teams: Coral Reefs and Coastal Carolinas (also includes Nitrogen and Wetlands components).

4.3.1. Types of Stakeholder/Decision-Maker Interaction

There are a myriad of approaches available for ensuring stakeholder/decision-maker involvement in the development of the DSF. A tool within SMARTe (Sustainable Management Approaches and Revitalization Tools – electronic) provides information for 66 different community involvement tools: http://www.smarte.org/smarte/tools/PublicParticipation/index.xml?mode=ui&topic=publicinvolvementaction. The EPA public involvement website: http://www.epa.gov/publicinvolvement/ is another excellent resource for information related to interactions with the general public (typically stakeholders in land and resource use decisions).

The **Coral Reefs team** is using a variety of stakeholder/decision-maker approaches to obtain information on their needs and preferences. The Coral Reefs team has already formed 5 focus groups around the DPSIR framework to assist them in the development of an integrated research program. Joint Coral Reef/DSF stakeholder/decision-maker workshops are planned for Southeast Florida, Puerto Rico, and the U.S. Virgin Islands. A workshop in the Florida Keys (at the Florida Keys National Marine Sanctuary) took place in June 2009. At this workshop, the Coral Reefs and DSF teams obtained a good understanding regarding the needs of the Sanctuary and good feedback regarding the workshop structure – both of which will be used to improve future workshops.

The workshops incorporate several information elicitation procedures including: flow charting decision-making processes, a value of information exercise, a social networking analysis exercise, small group breakouts to obtain input on the DPSIR and decision landscape framework, and a Q&A discussion regarding existing tools and models. Future workshops will incorporate lessons learned from the first. Stakeholder interviews and follow-up interactions will include a more specific elicitation of values and preferences to support Bayesian belief nets as part of the DSF.

The **Coastal Carolinas Team** will use many of these same techniques to interact with their stakeholders and decision-makers. The DSF team members will provide expertise and support of these interactions.

4.4. DSF Ecosystem Services Tools Database

An ongoing theme for the DSF Team is that planners and decision-makers are challenged to consider not only direct market costs, but also ecological externalities. There is an increasing emphasis on ecosystem services in the context of human well-being, and therefore the valuation and accounting of ecosystem services is becoming an integral component of economic efficiency. It is recognized that organizations and researchers continue to expand currently available tools that will be of value to the decision-maker for evaluating alternative approaches and outcomes of management actions, thus providing the decision-maker with greater levels of confidence that ultimate management actions will produce the desired outcomes. The Ecosystem Services Tools Database will maintain a collection of ecosystem services-related tools, approaches, models, etc., for categories of ecosystem services and decision type. The database is intended to bridge user needs with existing or planned tools that can be of direct use to the decision-maker.

4.4.1. Description, Purpose, and Intended Audience

Depending on the type of decision to be made, associated ecosystem services may be quantified by using a variety of approaches that could consider deterministic physical and chemical processes, known empirical relationships, and/or socioeconomic valuation methods. Existing lists and directories emphasize process modeling to evaluate results of water resources decisions, changes in mass and energy budgets, and other direct physical manipulations. These can be found on several governmental and non-governmental websites. In the context of decisions that affect ecosystem services in the more general sense, ecological externalities may be quantified using process models, but other tools and techniques may consider broader measures. The Ecosystem-Based Management Tools (EBMTools) Network (NatureServe 2008) has developed a database of tools that consider bundled ecosystem services emphasizing coastal and marine systems. The ESRP DSF Ecosystem Services Tools Database presented herein augments the scope of the EBMTools Network database by including non-coastal and marine systems and by including ecosystem services in the broad sense of decision support related to the USEPA's Ecosystem Services Research Program (http://www.epa.gov/ord/esrp/index.htm).

The DSF Ecosystem Tools Database is currently a collection of 235 tools that are designed to provide information across a wide range of disciplines to assist the decision-maker in making decisions that have the potential to impact ecosystem services. This database is designed to be flexible and expand or contract as new tools become available and older tools become obsolete. The database is being developed to provide the decision-maker with a suite of tools that may be useful in providing information that will have direct bearing on the management questions under consideration. The purpose is to provide an evolving searchable database of tools, approaches, and techniques that can be applied in analytic-deliberative decision support processes for improving decisions that may affect ecosystem services. This database is intended for users of varying levels of expertise. It will provide information about tools and will assist in the decision process. It is not intended to take the place of the decision-maker and their associated expertise.

4.4.2. Current status

As of June 2009, the Ecosystem Services Tools database contains approximately 235 records, and this number is increasing. Figure 8 shows the fractions of the total list by tool category (pie chart on the left). The Decision Support System Category is further broken out in the pie chart on the right. Additional information can be found in Appendix 5.

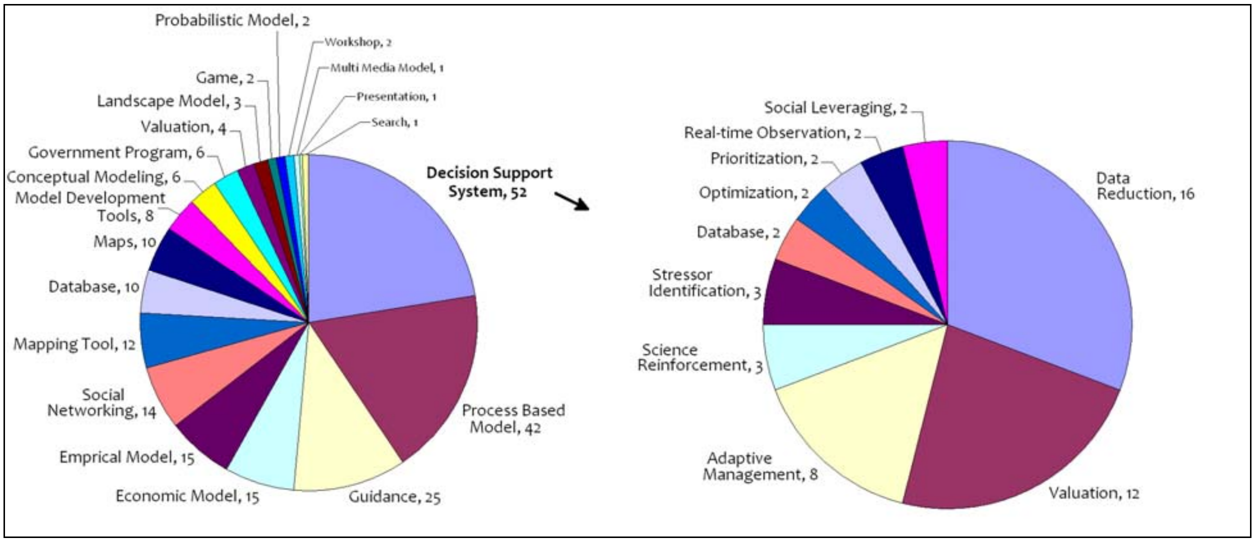


Figure 8. Listing of the categories of tools for the Ecosystem Services Tools Database.

As part of the DSF/Coral Reefs workshop in Key West, FL with clients and partners, the DSF Ecosystem Services Tools database was demonstrated as part of the Phase I development process. The demonstration used a subset of database tools that were relevant to Coral Reefs. During the workshop, we solicited comments on ways to improve the database to better suit the needs of Coral Reefs managers and decision-makers. These comments are currently being incorporated into the database. We intend to use the workshops as a key means to evolve the DSF Ecosystem Services Tools database to tighten its usability. The Tools database will serve as the link between DSF Team clients and partners and the tools that may assist them in decision-making.

4.4.3. Partnerships for the DSF Ecosystem Services Tools Database

The EBMTools database mentioned in Section 4.4.1 contains over 400 tools related to coastal and marine ecosystems. Only about 15 of these are common to the current ESRP DSF Tools database. Therefore, we see an opportunity for collaboration with the EBMTools group to bring the two tools databases together and thus expand the respective databases without having to engage in duplicative efforts. The EBMTools group is very welcoming of this collaboration, and we have begun discussions with the group on how best to do this.

The DSF team has also developed a relationship with EPA's Office of Environmental Information (EPA OEI). EPA OEI has established contracts with Lockheed Martin and subcontractors to establish the Environmental Modeling and Visualization Laboratory (EMVL). Among the strengths of this group is expertise in the design of databases and query interfaces. The DSF team has secured several hundred work hours for FY09 for our Phase I database development efforts and EMVL is making adjustments and “fine-tuning” the current MS Access database to prepare for a migration to the enterprise level MySQL database management system. It is expected that EMVL will incorporate comments received in external peer reviews and in DSF/Coral Reef workshops with clients and partners. We plan to extend our use of EMVL in FY10 and beyond.

We have used the services of the EPA Center for Subsurface Modeling and Support (CSMoS) to assist in populating fields of the database as tools have been added. We plan to continue to utilize CSMoS on a continuing basis as tools continue to be developed or discovered by the DSF Team.

4.4.4. Future Plans

The Ecosystem Services Tools database is scheduled to be migrated into the MySQL database management system in September, 2009. In FY 2010, the schema will continue to be improved and refined. It will be modified to allow greater expandability in the database structure. Also in FY2010, a web-based user interface will be developed to allow users to build a query to find a list of tools that can help meet their decision support needs, based on a series of questions. These will include questions about the type of decision to be made, the category (Matties et al.) of tool(s) needed, the temporal and special scales of interest, amount and type of data available, the user's scientific background, and the type of ecosystem being considered. The user interface will be vetted with participants in the decision-maker/stakeholder workshops and will continue to evolve.

In the next year, we will also focus on identifying additional research and model development needs by using the database to determine what already exists and what still needs to be developed. This will likely be done in partnership with the ESRP modeling, mapping, and monitoring teams using the problem statements developed by other ESRP projects.

The database will ultimately be coupled with the decision support framework to allow users to find tools that can be used for specific parts of the framework. This will begin in FY2010 and will be ongoing.

4.5. Social Network Analysis/Tools

4.5.1. Social Network Analysis – description, tested use, potential future use

> “Social network analysis is the mapping and measuring of relationships and flows between people, groups, organizations, computers, or other information- and knowledge-processing entities.” (Krebs 2008)

Social Network Analysis (SNA) has been used in the business world since the 1930s. Its intent is to improve productivity and organizational structure. With new software and analytical tools, it has gained wider use in studies of knowledge transfer, communication, collaboration, and decision science. It is a tool that can be used to support strategic collaboration, facilitate knowledge creation and transfer, and increase our capability to manage ecosystems and resources.

SNA enables users to determine direction of information/knowledge flow; task flow; and trust or energy flow. One can determine if a person is overly central or loosely connected and under-utilized. Divisive subgroups can also be identified.

SNA can be used to increase societal capacity to manage ecosystems and resources. It can:

- Identify and support leadership functions and gaps
- Increase participation by bringing in isolated teams or individuals
- Detect information bottlenecks.
- Identify opportunities for improving the flow of knowledge
- Accelerate the flow of knowledge and information across functional and organizational boundaries
- Improve the effectiveness of formal communication channels
- Target opportunities through which increased knowledge flow will have the most impact
- Raise awareness of existing informal networks
- Identify types of information that are communicated or not.

To use SNA, one must identify study questions and bounds; map network nodes and connections; analyze the network structure, content and flows; and apply new understanding to utilize, strengthen, or intervene. Figure 9 shows an example of an SNA developed for the DSF/Coral Reefs workshop in June 2009. Workshop participants were given an exercise where they identified:

- With whom they communicated frequently and infrequently
- The frequency with which they communicated (scale of 0-8, once a year to many times per day)
- The types of information they received from each person
- The value of information received (scale of 0-8 from no value to critical)
- The types of information they give.

Figure 9 allowed workshop participants to look at clusters of communication frequency between individuals (actual data included names, but only organizations were presented for sensitivity purposes). A clustering algorithm was run on the network. The thickness in arrows represents how often communication occurred (the thicker the arrow, the more often the communication). The colors of the nodes represent how the network clusters. In other words, the colors show the groups of people that are most connected to each other. For example, the blue cluster at the bottom of the figure gives us information about a person from Nova Southeastern University. This individual is connected to other Nova representatives, Broward County representatives, and a NOAA representative, but is disconnected from the main network. The diagram also shows that the Broward County individuals are not in communication with the larger network from the larger network's perspective. It would be interesting to investigate this perceived lack of communication. One way to do this would be to give the exercise to the Broward County individuals who were identified in the bottom cluster. With the figure, we can look for patterns and answer the following questions:

- Does the communication network serve needs well?
- Are any individuals or clusters of individuals poorly connected?
- Is critical information held outside the information network?
- Does the network support learning?

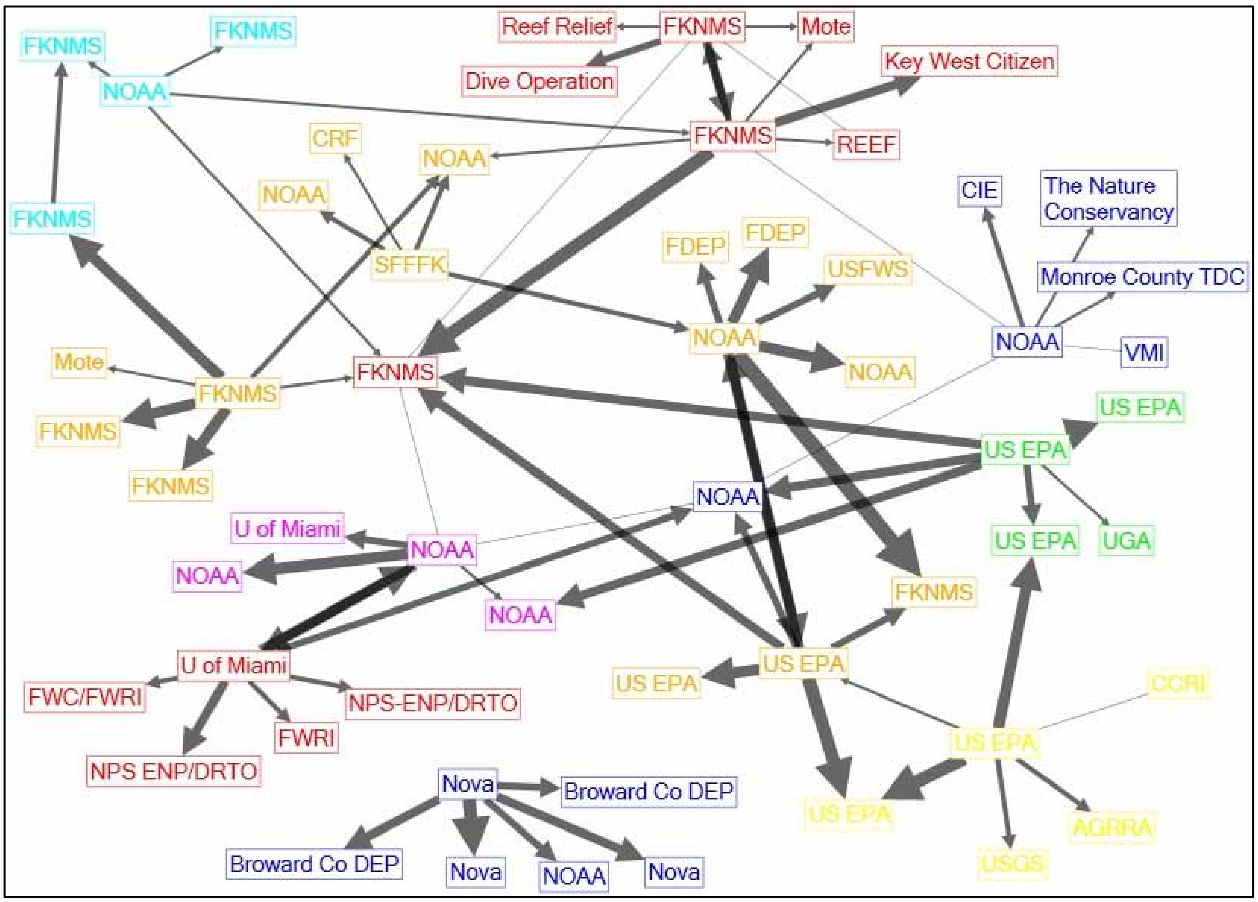


Figure 9: Social Network Analysis for the Florida Keys National Marine Sanctuary

The DSF team will continue to build its understanding and capability in the area of social network analysis.

4.5.2. Social Networking Tools

A variety of social networking tools (Facebook, MySpace, LinkedIn, etc.) are being investigated for their potential to bring ecosystem services stakeholders and decision-makers together in a social network to discuss common issues, learn from each other, and direct them to more robust, scientific websites. Different applications are being considered as well such as “send your friend a fish.” The application would contain fun facts about a particular fish, the ecosystem to which it belongs, and information about the type of ecosystem service it provides. Because knowledge and education often impact decisions people make, social networking tools are being examined by the DSF and OE teams as a way to educate the general public about ecosystems and the services they provide. This is a very minor part of the DSF team’s activities.

4.6. Decision Analysis and Value of Information (VOI)

A key part of our research efforts will be to explore and test the applicability of decision analysis methods for actual environmental decision problems. In particular, we will advance methods for identifying the most valuable new information, data collection, and research needed to support management decisions involving complex scientific issues in the context of a multi-stakeholder, deliberative process. Using the conceptual models and background information developed in our decision landscape and social networking efforts for the case study sites, we will formulate decision models that include both scientific and stakeholder input. The decision models will consider available management options, perceived relationships between management options and environmental outcomes (and the uncertainty present in these relationships), and valuations for alternative outcomes derived from economic studies and stakeholder elicitation. We will then estimate the potential value-of-information (VOI) that could be provided by further studies designed to reduce uncertainty and clarify the decision options. Our study will consider both traditional VOI measures from the decision analysis literature (based on a single decision maker) and a new proposed measure that addresses the probability that the study result will allow stakeholders who initially disagree on the preferred management option to reach agreement once the study is completed and the results are in. For this assessment, stakeholders are elicited for their beliefs regarding the accuracy and reliability of the proposed scientific studies. This will provide useful feedback to the ORD and other agencies as to the types of studies that should be pursued and the measures needed to ensure that stakeholders will support and trust their outcomes. In this way the proposed decision analysis/VOI studies will support environmental management plans that include ongoing monitoring, research, adaptive scientific learning, and deliberative participation.

4.7. Quality Assurance for DSF

The DSF will be a web-based structure for organizing and delineating components within a land and/or resource use decision. The components will use Bayesian analysis approaches and must be able to be integrated to allow decision-makers to understand and evaluate different land and resource use options. This will require statistical software to be used and/or developed. For any software development effort, a Quality Assurance Project Plan (QAPP) must be prepared. The DSF team will prepare a QAPP in accordance with the National Risk Management Research Laboratory's (NRMRL's) QA requirements and EPA information security requirements. The QAPP will be reviewed and approved by QA staff and information security experts. Once approved, the QAPP will be reviewed annually to determine if any modifications are needed.

A QAPP for the tools database has already been reviewed and approved by a NRMRL QA Manager. This QAPP will be reviewed annually to determine if it requires modification.

Models, data, and analysis tools developed by other ESRP personnel are the responsibility of the tool developer.

5. Phase 3 and Beyond – Future Plans

As indicated in Section 4.1 above:

By 2016, we envision a comprehensive, systems level framework that will allow decision-makers and stakeholders to evaluate planned land and resource use management options to determine their impacts on ecological sustainability (using bundled ecosystem services and production functions), social sustainability (including human well-being, quality of life and sense of place), and economic sustainability.

After Phase 2 is completed, we will work with other ESRP and non-ESRP projects to continue to develop and refine the DSF so that by 2016, the framework will be usable across the nation to evaluate a variety of land and resource use management options.

6. Limitations and Bounds

EPA needs in the area of decision science are large, and ORD's human resources in decision science are currently limited. Current and projected ORD budgets through 2010 severely limit ORD's ability to contract outside experts in decision science. We will have to make the best use of existing ORD, Regional and Program Office expertise in decision science, use postdoctoral positions to acquire expertise, set decision science as a high priority in ORD staffing plans, and find potential partners. In this context our approach is to demonstrate the Agency's recognition of the need for decision science research and to set yearly objectives toward this goal. These objectives are obtainable given the current constraints, which include:

- Lack of resources. We lack extramural funds to support workshops and other face-to-face interactions for all ESRP projects (only a few can be supported). We lack travel money for in-house personnel to travel to workshops and/or meet with other ESRP stakeholders and decision-makers. We lack dedicated, full time in-house personnel.
- Bounding our efforts: The ESRP is a very broad program. We have attempted to bound our efforts by focusing on land and resource use decision-makers; however, this is still very broad and will remain a challenge as the program evolves. This is discussed in more detail below.
- Integrating science and human values/judgments: This is a common decision science challenge that we too must meet.
- Limitations imposed by EPA: Currently, EPA restricts computer software that can be used. EPA also requires Information Collection Request approval to

perform surveys, a tool that is typically used by social scientists to collect information from decision-makers and stakeholders. Survey approval can take up to 3 years to receive.

- Lack of in-house expertise in social and decision sciences: ORD is attempting to increase its capability in these areas, but it will take time.

With respect to determining the bounds and limitations on the DSF research itself, under the current vision, it is necessary to answer the following questions:

- What do decision-makers (both internal and external to ESRP) need? The DSF needs to include information and tools that are desired by decision-makers from a local to a regional level.
- What has already been done well? The DSF will identify existing tools that meet user needs and identify where gaps exist. We will inform other ESRP theme and project leads of these gaps so research can be focused to meet these.
- What are the technical constraints? The DSF needs to be designed within the constructs of today's information technology, yet be flexible enough to mature and grow as technology improves. The DSF team has initiated an IT sub-team to help address this question.
- What are the legal constraints? The DSF needs to provide information and tools to help decision-makers make decisions. Appropriate disclaimers will need to be developed and maintained. The DSF team will also need to work with a variety of partners (both internal and external to EPA) to accomplish its goal and develop partnership agreements. The DSF team will work with EPA's Office of General Council and ORD's Office of Science Policy to address these issues.

7. Measures of Success

The fully functional DSF is planned to be released in 2016. Web-statistics and testimonials will be collected for an additional period of time yet to be determined. The DSF team will attempt to collect information related to how the DSF:

- Informs the protection, restoration, and enhancement of ecosystem services
- Enables decision-makers to evaluate management options inclusive of the value of ecosystem services and human health and well-being
- Encourages the consideration/incorporation of ecosystem services in decisions at the national/policy level scale and at the local/regional/tribal scales.

ESRP will also attempt to measure additional positive outcomes, such as:

- An increase in the number of decisions that include traditionally non-market costs and benefits
- Increased availability of ecosystem services
- Increased resilience of natural systems

Appendix 1 – Response to Comments from SAB

The SAB provided several comments with regard to the Decision Support efforts put forth in the original MYP. These comments were in six primary areas: (Ojeda-Martinez et al.) Lack of needed in-house expertise; (2) combining the DSF with OE; (3) adequately describing how the DSF would work; (4) concerns about feasibility of developing the DSF; (5) developing connections and utilizing outside partners; and (6) adequately defining potential clients. The DSF team considered all of the comments made by the SAB and we have addressed each area as described below.

- EPA's Office of Research and Development (ORD) recognized early that we did not have all the expertise in-house to accomplish all that was needed in the development and implementation of Long Term Goal 1 and especially the DSP(F). The SAB comments also pointed this out. The DSF team has been working diligently to bring in outside expertise to fill in the gaps that exist and impede the development of the DSF. The ESRP has brought on two expert hires form Carnegie Mellon University and one from Duke University to assist. ORD and the DSF team have organized a workshop and a series of webinars from outside experts in the field of decision science/analysis to bring their perspectives to the table. Two divisions in the National Risk Management Research Laboratory (NRMRL) are building up their capabilities in the area of decision analysis. The DSF team continues to identify gaps still unfilled in this process and search for experts to fill those gaps.

- The SAB suggested that the DSF and OE groups be combined into one team. The ESRP originally had these two groups combined but quickly found that the amount of work to be done in each of these areas necessitated the need for two full teams. The DSF team needs to work directly with decision-makers and stakeholders to develop the DSF while the broader ESRP team needs to ensure that decision-makers and stakeholders are included in ESRP efforts and to educate people about ecosystem services in general. The ESRP recognizes that the DSF and OE teams still need to be closely linked, and to that end the two teams have several overlapping team members. The teams will continue the strong ties and collaboration to accomplish the ESRP goals.

- The SAB identified the need to provide greater detail on how the DSF would work. As indicated above, the "Decision Support Platform" team is now the Decision Support Framework team. The DSF team has refocused its efforts to concentrate not on an on-line platform, but on collecting information and understanding what decision-makers and stakeholders need or want. The intent of this revised implementation plan is to detail the current approach for developing a DSF.

- The SAB raised concerns regarding the feasibility of accomplishing Long Term Goal (LTG) 1 (see the ESRP Multi-Year Plan at: http://epa.gov/ord/htm/multi-yearplans.htm). This was based on the relatively short time for this goal to be completed, the lack of available expertise, the lack of resources allocated to this effort, and that this goal, being dependent on much of the other work being conducted concurrently, should be re-classified as a long-term objective. The DSF team agrees with this assessment and we have discussed these concerns with our upper management. This final decision is still being considered at that level. The DSF team has suggested pushing back the final deliverable of this effort to coincide with the intent expressed by the SAB. The DSF team is looking to partner with outside groups in an effort to leverage our resources with these groups and further the development of the DSF.

- The DSF Team has been working on developing interactions and connections with potential outside partners. These efforts have focused on academics, private sector companies, other governmental agencies, professional societies, and international professionals working in the area of ecosystem services and decision analysis. These were all areas identified by the SAB where the DSF team could do a better job in broadening the reach and expertise of the DSF effort. Examples include:

  - Through interactions with SETAC, DSF team members are putting forth sessions at their annual meetings focused on ecosystem services, developing a Global Science Advisory Committee to provide a platform for researchers across the globe to share and exchange ideas and information regarding ecosystem services, and working with the steering committee to set up special symposia to discuss ecosystem service concepts both in Europe and the United States.

  - Through interactions with the German Helmholtz Centre for Environmental Research (UFZ), DSF team members are learning how others apply integrated multi-disciplinary research (IMDR) to solve problems of broad national significance. Since 2006, the UFZ has been applying IMDR to develop a tool for managing contaminated "mega-sites." The lessons learned are universal and can be applied to ESRP's integrated multi-disciplinary efforts.

  This is a dynamic and ever evolving process that will continue throughout the life of the DSF effort.

- The process to adequately identify potential clients is a constant challenge. The DSF Team plans, over the next several years, to conduct workshops with the place-based areas and the coral reefs, nitrogen and wetlands groups to identify and incorporate these clients into the development process of the DSF. The DSF team participated in a joint OE/Coastal Carolinas workshop in January 2009. A joint Coral Reef/DSF workshop was held in mid June 2009. Out of these workshops the DSF team has a better understanding regarding who the specific clients of the DSF efforts may be. While we can certainly identify groups that will help develop and use the products delivered by the ESRP and especially the DSF, it is more difficult to specifically identify names and individuals that will use these products. This can only be accomplished at this level by conducting these types of workshops with other ESRP teams and engaging these individuals and groups face to face. The DSF team will rely on the OE team to help us reach clients beyond the ESRP.

The DSF team is working diligently to not only address the letter of the SAB comments but the spirit of these comments as well. This process will continue through the life of this effort with the goal of providing a top notch DSF that will support the decision needs of our potential clients.

The DSF team also received review comments from other implementation plan reviewers. The DSF team has addressed these comments in this revised implementation plan and has prepared a point by point response to these comments back to the reviewers.

Appendix 2 – Defining the Decision Problem and the Decision Landscape (Context)

The process of environmental decision making requires use of good science, stakeholder participation, and learning, and it must be transparent. Traditionally, the science has been the focus of this process, but often, the process has failed because of the other less emphasized parts of this decision making process --the lack of transparency, lack of stakeholder participation, and the lack of learning or understanding (not just of the science but of the various stakeholder perspectives). Therefore, "getting the science right" may be a necessary component but, alone, it is not sufficient for environmental decision making. The process of environmental decision support requires the application of appropriate environmental databases, mapping tools, models, and economic valuation methods. This may be referred to as “getting the science right.”(National Research Council 1996). However, prior to this, critical steps occur in the identification of assessment participants, the framing of issues for evaluation, enumeration of decision alternatives, and the determination of appropriate metrics for comparing projected outcomes. NRC (1996) characterizes this as “getting the right science.” It may also be viewed as providing a proper understanding of, and tools responsive to, the decision landscape of an environmental issue. The proposed DSF research will seek to provide a framework that enables understanding of the role of different participants in the decision problem, and the need for an adaptive assessment that responds to their decision support needs.

Characterization of a decision landscape is made recognizing that various groups and individuals provide inputs to environmental decisions in different ways, and that these inputs evolve over time along with the state and quality of the ecological system. Examples of key participants in an environmental decision include:

- Industrial producers that discharge contaminants that affect the resource of interest;
- Direct users and beneficiaries of the ecosystem, such as commercial and recreational fishers, hunters, farmers with fields within the study zone (“upstream” farmers would be included in group 1), loggers, biofuel producers, hydropower interests, and park visitors;
- Information gatherers and providers regarding the state of the ecosystem and its services, including scientists in government agencies such as the USGS, NOAA, USDA, EPA, and private, nonprofit, and academic researchers;
- Government agencies charged with resource stewardship and regulating activities affecting the environmental system;
- Public groups or organizations with advocacy positions regarding the environmental resource and its various uses.
- The general public and its representatives who may bear the costs (and receive the broader benefits) of various economic and regulatory decisions regarding the protection and management of the resource.

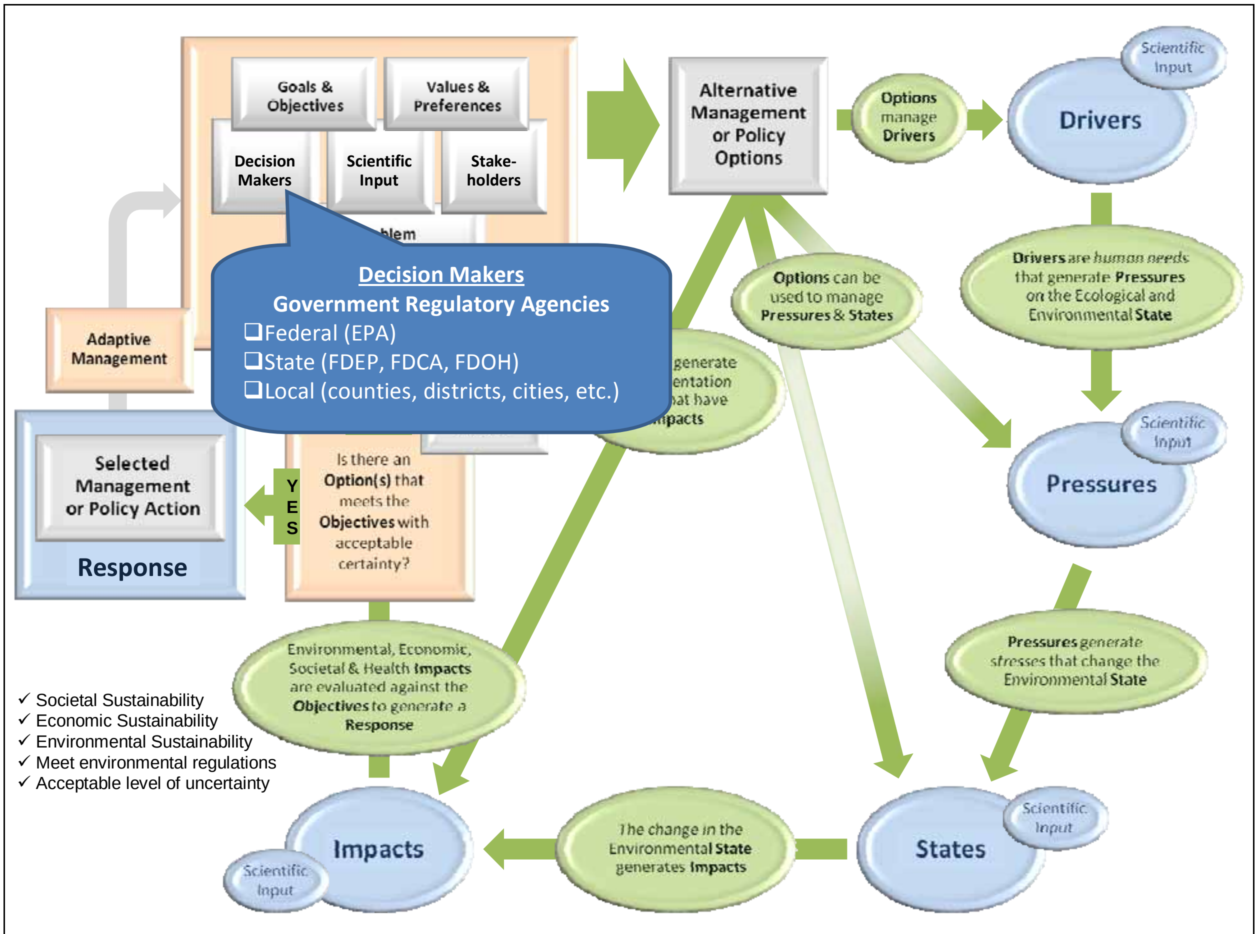
While environmental decision support has traditionally been viewed as being provided by those in bullet 3, for those facing decisions in bullet 4, the broader potential for decision-support efforts to support improved decision making across the range of problem participants is increasingly recognized. It is also evident that effective prediction of the outcomes of alternative management decisions requires an informed consideration of the manner in which the activities of each of the six groups of participants might co-evolve along with the state of the natural ecosystem.

Analytic-deliberative approaches that facilitate transparency, stakeholder inclusiveness and learning provide a better process for informed decision making. Choosing among the decision tools, methodologies and approaches is difficult because it requires users to be aware of methodological nuances that may only be known to the designer or scholarly user. For example, use of cost-benefit tools or approaches are extremely useful to better understand monetary tradeoffs, but if the user is not careful, he/she may be monetizing decision criteria that should not be monetized or that don't make sense when monetized. Other aspects of decision tools can be even more nuanced. Recognition (and documentation) of the decision landscape can provide a basis for a better-informed, better-focused set of tools in the proposed DSF. Are the parties to a decision and their roles clearly delineated by law or regulation? Does an agency with decision authority seek a consensus among various stakeholders? Are decisions by many disaggregate decision-makers (e.g., homeowner, farmers, or consumers) critical to the environmental outcome – is effective risk communication a part of the planned management strategies? Are decision metrics specified by law or prior agreement? Are management options limited to a set of predefined alternatives, or is there the flexibility to propose new approaches? Do the various stakeholders trust and utilize common sources for data and scientific assessment, or are there competing studies financed by two or more parties?

Each of these elements of the decision landscape has implications for choosing an appropriate decision-support methodology and tool. Consider the case of a single decision-making agency with the requirement to choose a “cost-beneficial” management option. Needs include estimates of the economic costs of various options and the environmental benefits projected to accrue from implementation of these options. To make the projected costs and benefits commensurate and directly comparable, valuation of improved (or lost) ecosystem services will be needed. However, the distribution of costs and benefits among different segments of the population may not be important – it may be sufficient to estimate only the aggregate (societal) net benefits. In contrast, consider an environmental problem where multiple conflicting stakeholders must reach a consensus on an effective management strategy. Disagreements could include which of numerous metrics for evaluation should be considered and how they should be weighted, the suite of possible management alternatives that should be considered as possible options, and maintaining conflicting scientific views of the current and projected state of the ecosystem and its services. Decision support for this type of problem is much more complex, requiring methods for multiattribute, multistakeholder tradeoff analysis; generation of alternative management options and future scenarios; and sensitivity and uncertainty analysis to show the importance of different views of the science and the potential value of information for reducing uncertainty and resolving conflicts. Many decision problems will lie between the two cases considered here – the DSF will support the range of decision-support tools needed to address them. The DSF will also provide a framework for decision-makers, interested parties, and assessors to explicitly delineate the decision landscape applicable to their problem and to choose the suite of tools best suited for their subsequent decision-support needs.

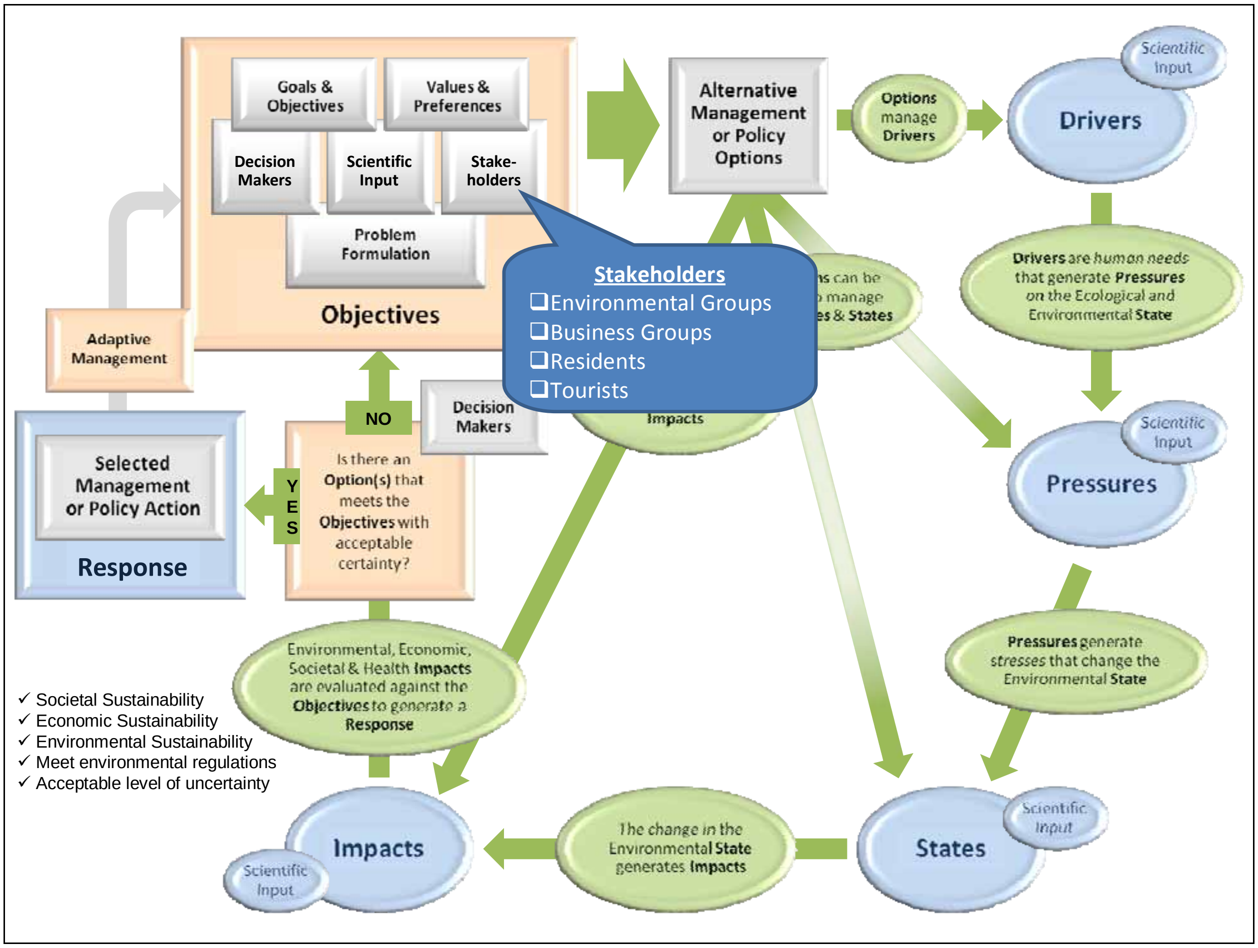
Appendix 3 – Hypothetical Application of the DSF to Address Nutrient Loads in the Florida Keys – Simple Example

In this hypothetical example, nutrient loading to near-shore waters in the Florida Keys needs to be reduced. We will use the DSF schematic to demonstrate how management options can be evaluated by decision-makers. Note that this example is for illustrative purposes only.



A3-Figure 1: Decision Makers

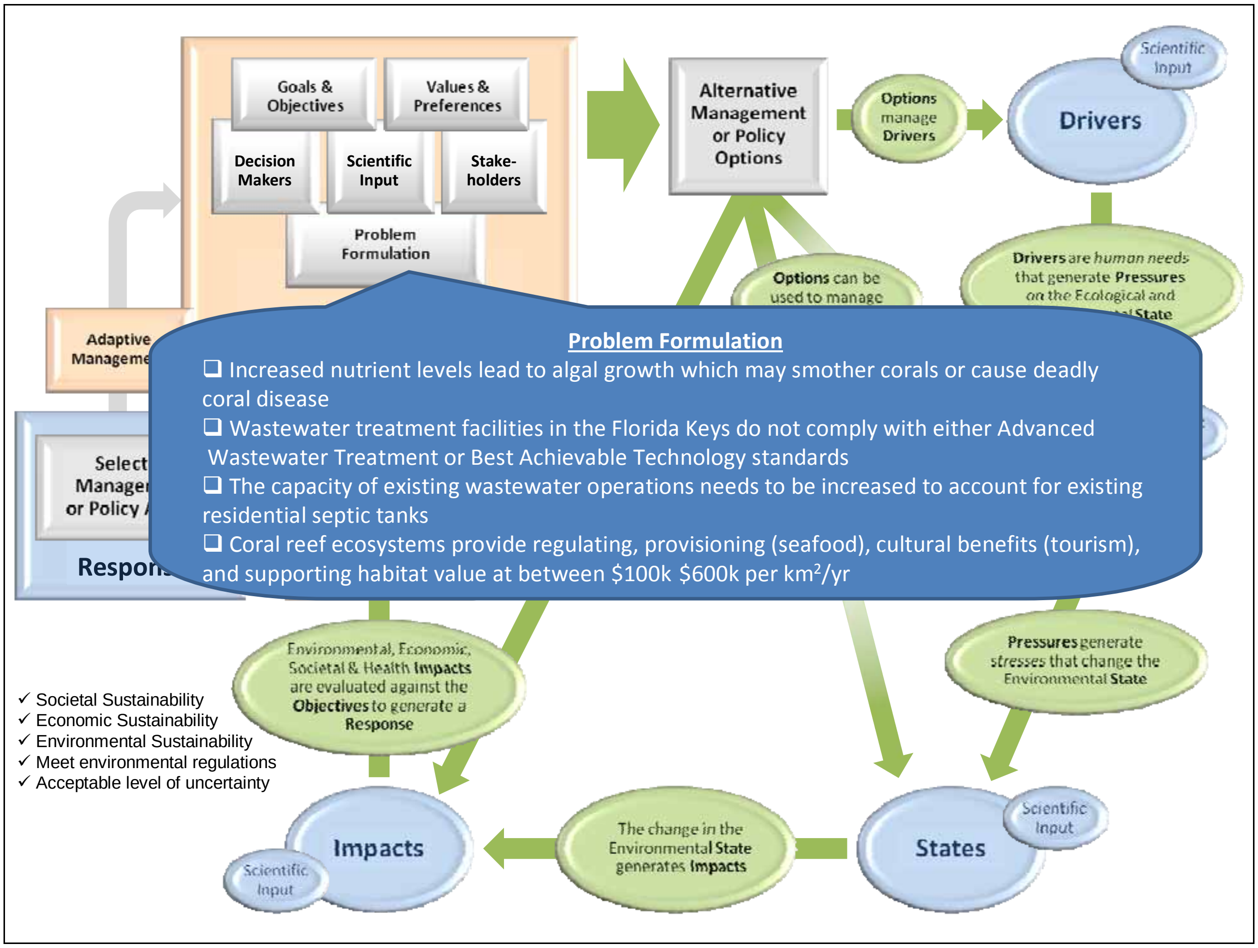
The decision-makers for this problem are largely federal, state, and local government regulatory agencies.



A3-Figure 2: Stakeholders

Stakeholder groups include:

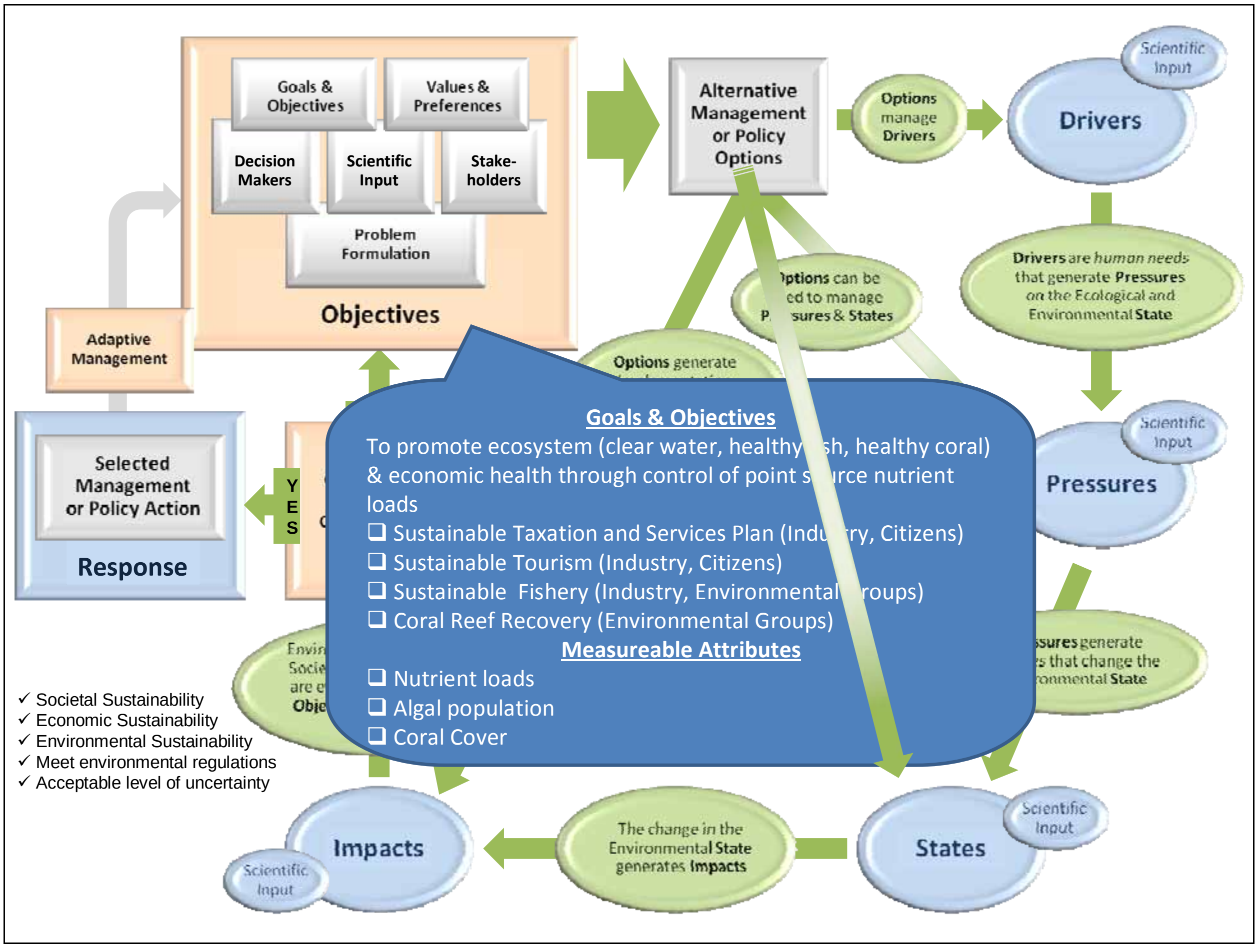
- Environmental groups that represent both
    - local interests and
    - the values of citizens not located in the Florida Keys, some of whom may never visit the Keys, but still value healthy coral reefs
- Business groups that represent a wide variety of interests including fisheries, snorkeling operations, hotels, etc.
- Residents whose interests include recreation, income, taxes, and services
- Tourists whose interests include healthy coral, clear water, affordability



A3-Figure 3: Problem Formulation

Interaction between decision-makers and stakeholders help to define the various components of the issue.

- Increased nutrient levels lead to algal growth which may smother corals or cause deadly coral disease
- Wastewater treatment facilities in the Florida Keys do not comply with either Advanced Wastewater Treatment or Best Achievable Technology standards
- The capacity of existing wastewater operations needs to be increased to account for existing residential septic tanks
- Coral reef ecosystems provide regulating, provisioning (seafood), cultural benefits (tourism), and supporting habitat value at between \$100k-\$600k per km^2/yr.



A3-Figure 4: Goals and Objectives

A collaborative process between decision-makers and stakeholders is used to define values and preferences, help formulate the problem, and develop a set of objectives that can then be used as the target for a set of plausible management options. Measureable attributes are also defined.

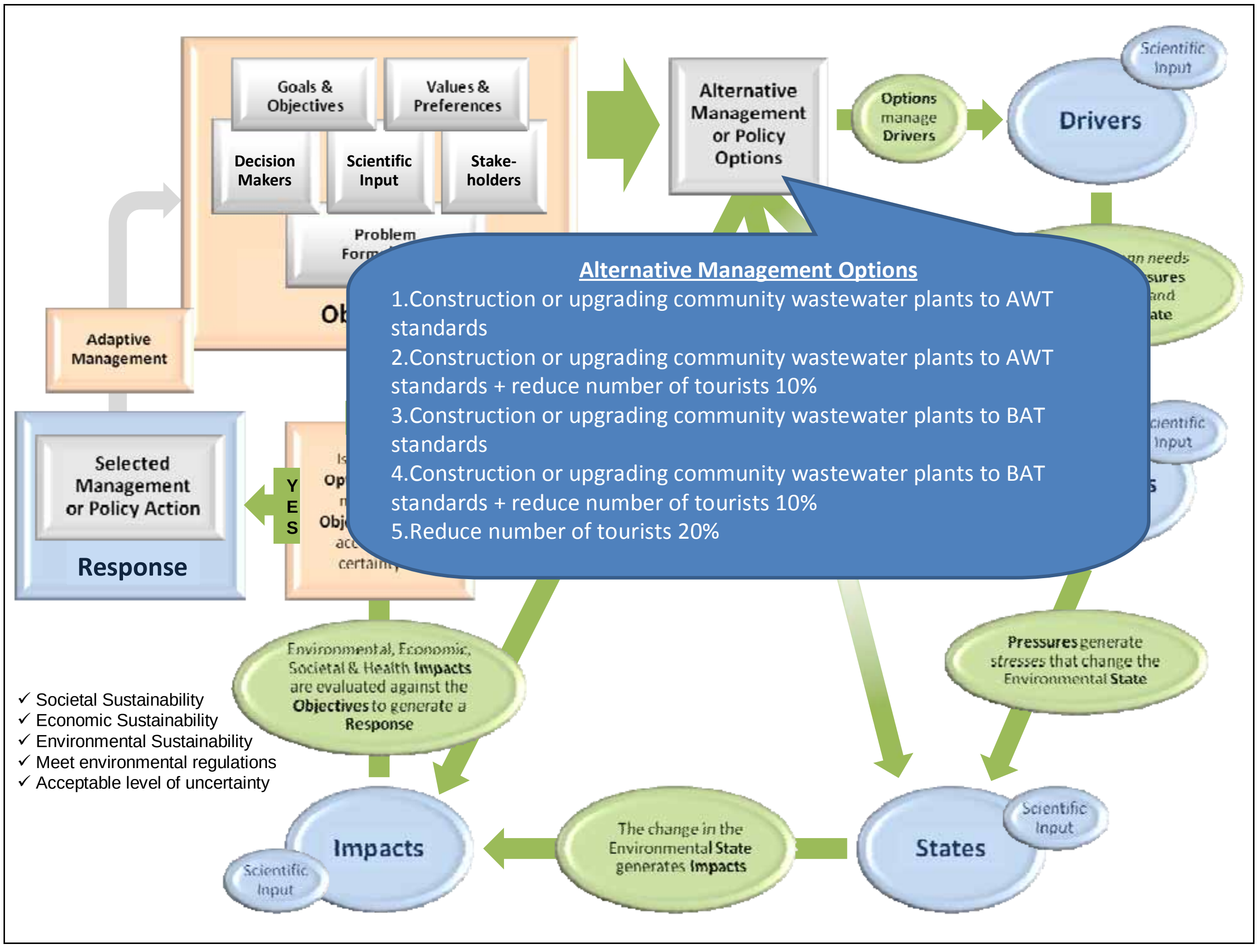
Goal: To promote ecosystem (clear water, healthy fish, healthy coral) and economic health through control of point source nutrient loads.

Objectives:

- Sustainable Taxation Plan (Industry, Citizens)
- Sustainable Tourism (Industry, Citizens)
- Sustainable Fishery (Industry, Environmental Groups)
- Coral Reef Recovery (Environmental Groups)

Measureable Attributes:

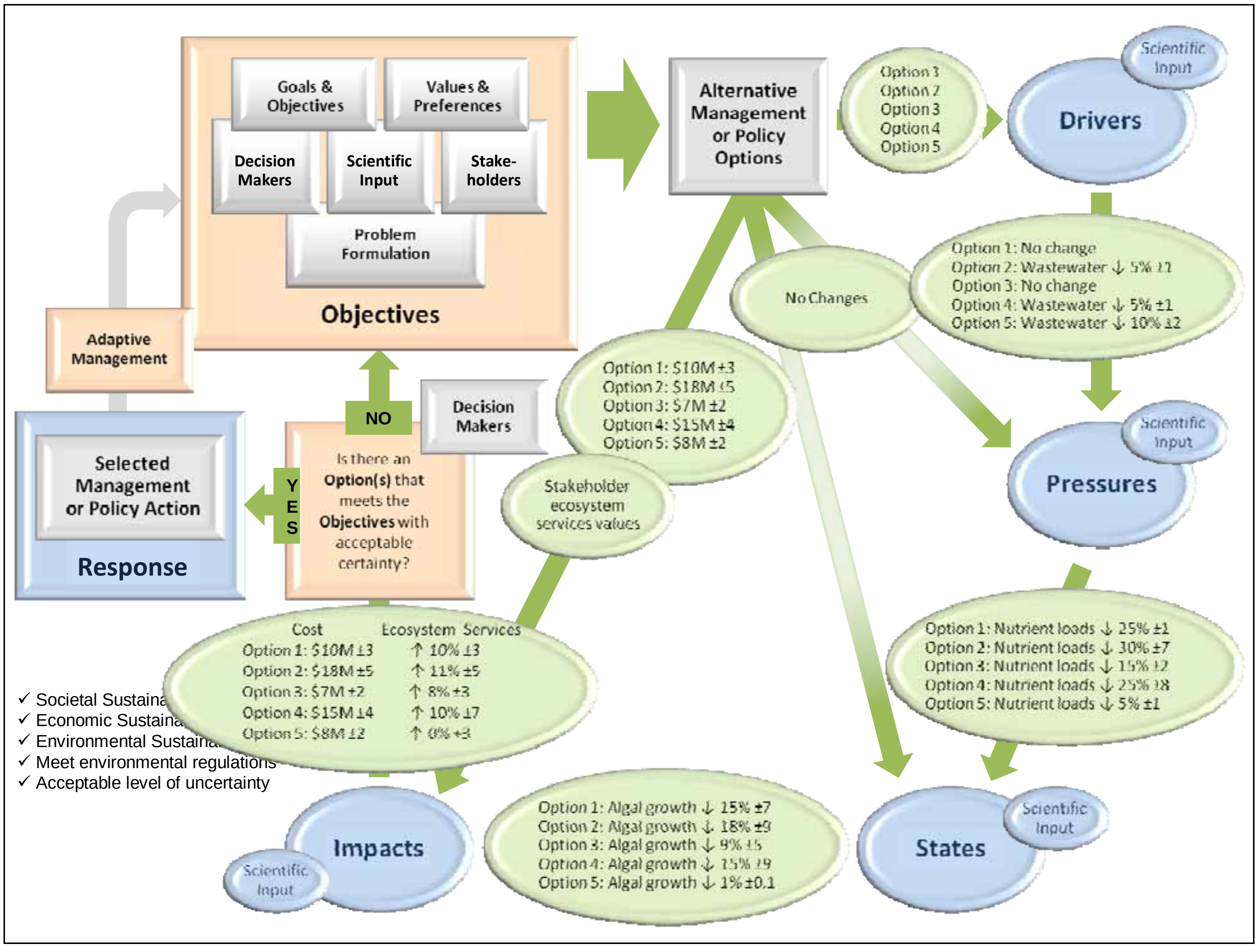
- Nutrient loads
- Algal population
- Coral Cover



A3-Figure 5: Alternative Management Options

Five management options were identified that could potentially meet the objectives defined above. These management options include a combination of building or upgrading wastewater treatment plants to Advanced Wastewater Treatment (AWT) or Best Available Technology (Turner et al.), and reducing the volume of wastewater by reducing the number of tourists visiting the Florida Keys.

1. Construction or upgrading community wastewater plants to AWT standards
2. Construction or upgrading community wastewater plants to AWT standards and reducing the number of tourists by 10%
3. Construction or upgrading community wastewater plants to BAT standards
4. Construction or upgrading community wastewater plants to BAT standards and reducing the number of tourists by 10%
5. Reducing the number of tourists by 20%



A3-Figure 6: Evaluation through DPSIR

The 5 management options are now evaluated through the DPSIR process.

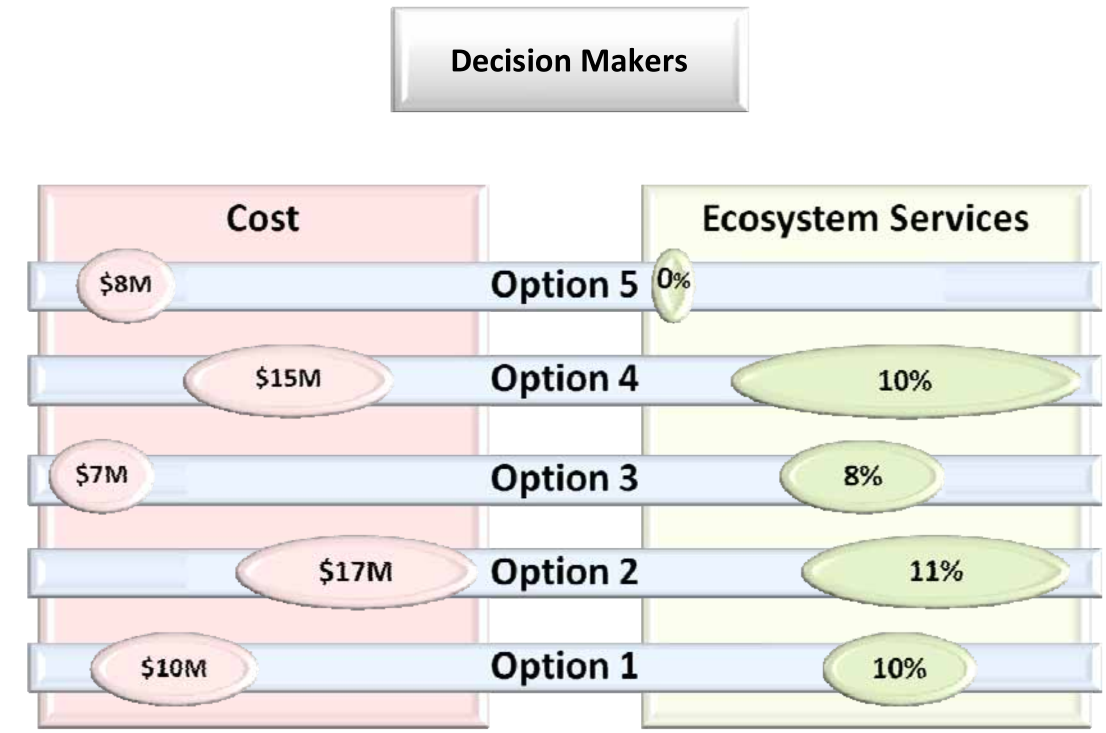
1. Construction or upgrading community wastewater plants to AWT standards
2. Construction or upgrading community wastewater plants to AWT standards and reducing the number of tourists by 10%
3. Construction or upgrading community wastewater plants to BAT standards
4. Construction or upgrading community wastewater plants to BAT standards and reducing the number of tourists by 10%
5. Reducing the number of tourists by 20%

The major *Driver* in this example is sewage disposal. The management option of “reducing tourists” can reduce *Drivers* by reducing the volume of wastewater being generated. In this example, WWTPs do not impact the overall volume of wastewater being discharged. The two wastewater treatment technologies in combination with tourist reduction reduce the *Pressure* of increased nutrient loads. The percentage decrease in nutrient loads is a function of both the volume of wastewater and the ability of each of the treatment types to reduce the nutrient concentrations in the effluent.

The reduction in nutrient loads generates a change in *State* of the algal population. This change in *State* is estimated using a model relating algal growth to nutrient concentrations. The complexity of this model can range from a simple empirical model to a 3D process model with tidal hydrodynamics. The model complexity needed is determined by the uncertainty level required for the decision-makers to make a decision. The basic process is to start with the simplest model and add complexity through a value of information analysis that provides a measure of the value of reducing uncertainty by increasing complexity and the resources required to support this increase in complexity (including data requirements).

The *Impact* generated by the change in *State* (change in the algal population) generated by each decision option is then evaluated. Our measure of *Impact* is based on changes in ecosystem services. The value of this change in ecosystem services is based on the *Values and Preferences* elicited from *Stakeholders* in the initial *Objectives* hierarchy development. The costs of implementing each of the management options are compared with the changes in ecosystem value generated by each option. The decision-maker is then left to choose the option that best meets the *Objectives*.

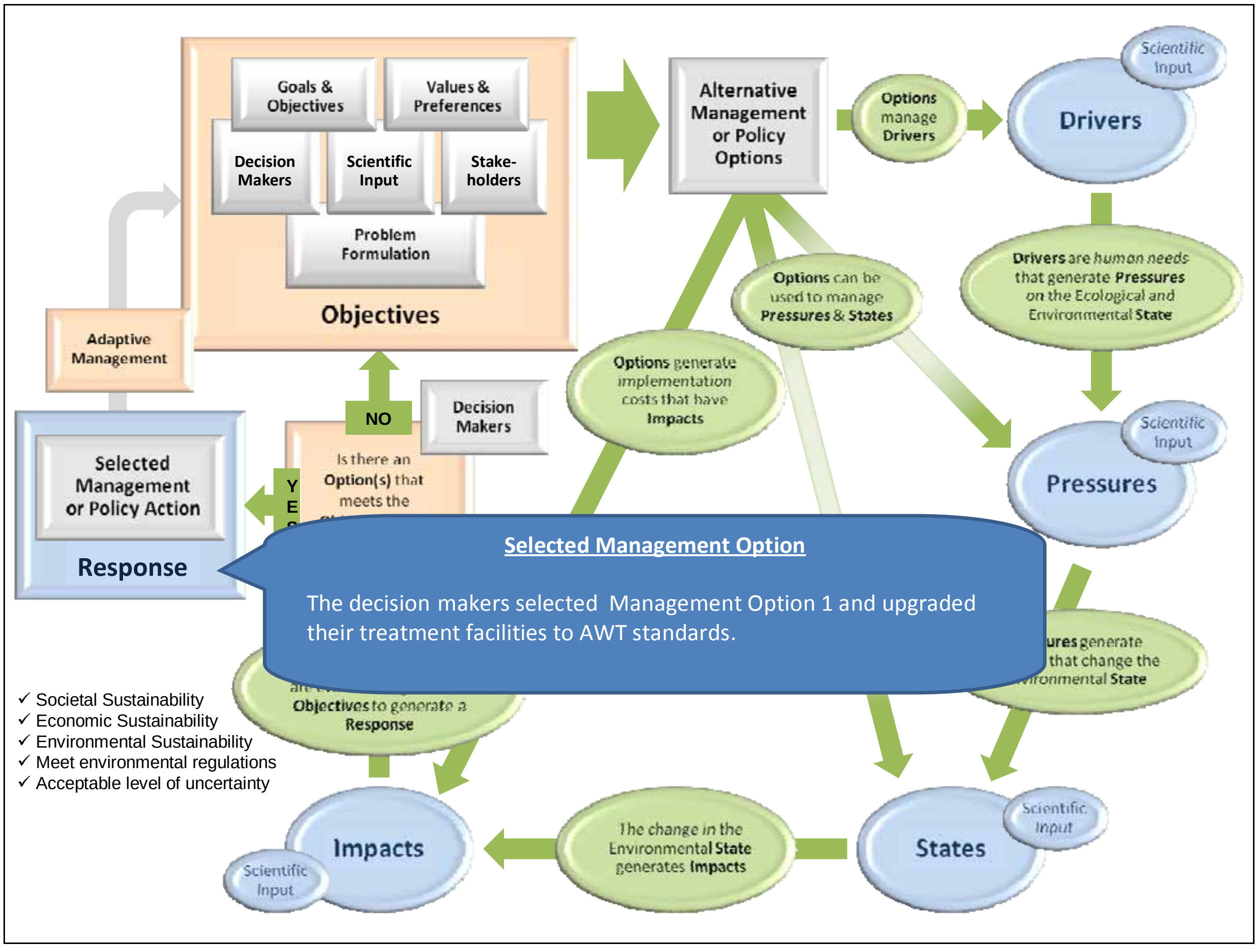
Note that the figure above includes a measure of uncertainty for each of the measureable attributes.



A3-Figure 7: Evaluating Trade-offs

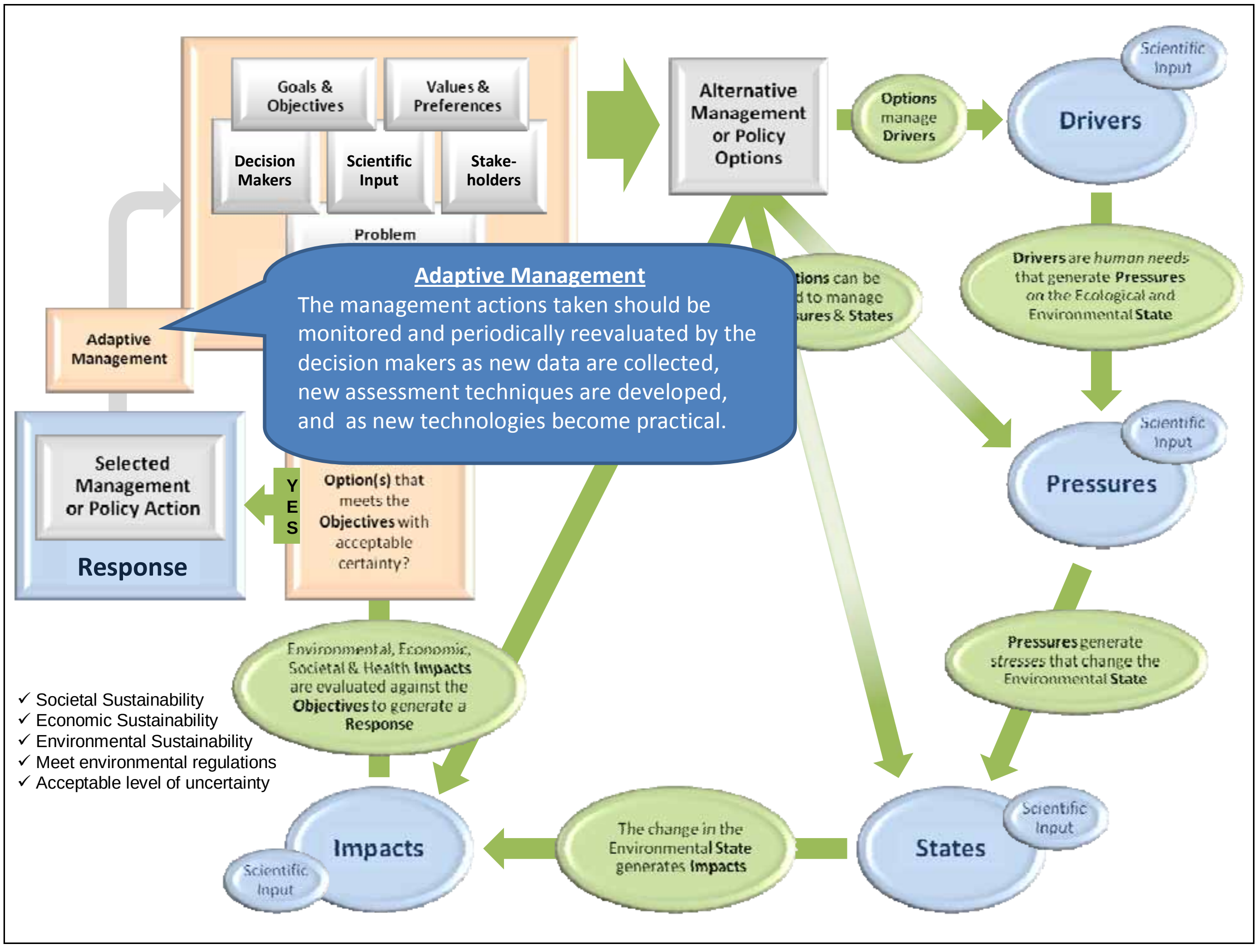
Option 5: Reducing the number of tourists by 20%
Option 4: Construction or upgrading community wastewater plants to BAT standards and reducing the number of tourists by 10%
Option 3: Construction or upgrading community wastewater plants to BAT standards
Option 2: Construction or upgrading community wastewater plants to AWT standards and reducing the number of tourists by 10%
Option 1: Construction or upgrading community wastewater plants to AWT standards

This figure depicts, on the left-hand side, the cost of each option including the calculated uncertainty (denoted by the oval length). The right-hand side depicts the increase in ecosystem services with associated uncertainty (again denoted by the oval length). The figure illustrates the trade-off the options provide between increasing ecosystem services and cost. For example, Option 3 is expected (based on the mean cost of $7M) to be the least expensive while providing an expected 8% average increase in ecosystem services. The uncertainty for Option 3 is low relative to the other options. Option 2 has a large cost uncertainty and a relatively high expected increase in ecosystem services with an accompanying high uncertainty.



A3-Figure 8: Selected Management Option

The decision-makers selected Management Option 1. This option included construction or upgrading community wastewater plants to AWT standards. This option met the basic objectives developed by the stakeholders and decision-makers. As can be seen in the previous figure, Options 3 and 5 were lower cost than Option 1 but did not provide a level of ecosystem services that the decision-makers felt met the objectives. Option 2 potentially could provide higher ecosystem services but also could provide lower ecosystem services because of the level of uncertainty. The decision-makers felt more comfortable with the level of uncertainty associated with Option 1.



A3-Figure 9: Adaptive Management

Adaptive Management
The success of the treatment plant construction or upgrades in meeting the objectives are continuously re-evaluated through monitoring. This action is also re-evaluated as new data are collected, new assessment techniques are developed and new technologies become available and economically feasible.

Role of Scientific Input in Decision Problem: Characterizing Current and Future Resources

	Variables	Current Knowledge	Research Needs
	• **Population Growth** • **Land Use** • **Economic Activity** • industry • agriculture • recreation/tourism	• **Census data** • **USGS land use/GIS data** • **BEA/Census economic data** -water, energy, material use (e.g., fertilizer)	• **Scenario Development:** - Future population - Future economic activity - Land use/land cover projection model
	•**Water use, diversion** •**WW discharge rates** - N, P, BOD, TSS, toxics • **NPS loading rates** • **Impingement** - boating, diving, etc.	• **Inventories** -cesspits, OSS's, package plants, municipal plants • **NPDES permit data** • **Compliance monitoring** • **NPS studies**	• **Scenario Development:** - water use - wastewater loading rates - NPS loading rates - impingement projections
Environmental	• **Freshwater flow rates** • **Ambient WQ** - N, P, Algal, DO, TSS, toxics	• **USGS flow monitoring** • **Fed/State WQ data** • **Special studies** -e.g., FL International U	**Statistical analysis** - further data as needed
Ecological	•**Coral Cover/Health** •**Fish Species Presence and Abundance**	• **Coral reef monitoring** - FWRI, NOAA • **Volunteer monitoring** - Ocean Conservancy	• **Statistical analysis** - further data as needed •**Marine Health Monitoring** - e.g., Scripps Inst.

A3-Figure 10: Characterizing Current and Future Resources

Acronym List (by column):

WW: Wastewater
N: Nitrogen
P: Phosphorus
BOD: Biochemical Oxygen Demand
TSS: Total Suspended Solids
NPS: Non-Point Source
WQ: Water Quality
DO: Dissolved Oxygen

USGS: United States Geological Survey
GIS: Geographic Information System
BEA: Bureau of Economic Analysis
OSS: On-site Septic Systems
NPDES: National Pollutant Discharge Elimination System
FWRI: Fish and Wildlife Research Institute
NOAA: National Oceanic and Atmospheric Administration

This and the following chart provide an illustrative example of the role of scientific information in the Florida Keys wastewater decision problem. Both charts draw from scientific research studies described in the Florida Keys National Marine Sanctuary (FKNMS) management plan and from the greater scientific literature. The chart above describes the role of scientific input in characterizing current and future resource conditions. It is organized according to the DPSIR framework (first column).

- The second column includes the variables of interest
- The third column includes the state of current scientific knowledge on the variables
- The last column includes research needed for decision support

Drivers

- Variables may include population growth, land use, and economic activity
- Existing data may be obtained from the Census, USGS, and BEA/Census
- Research needs may include scenario development for each of the three variables for use in modeling

Pressures

- Variables may include water use, wastewater discharge rates, and pollutant loading rates
- Existing data may include inventories, NPDES permit data, and compliance monitoring
- Research needs may include scenario development for each of the variables for use in modeling

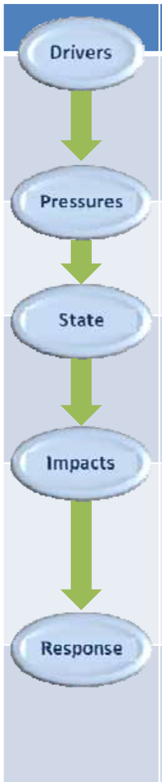
Environmental State

- Variables may include freshwater flow rates and ambient water quality and parameters
- Existing data may include flow monitoring and water quality data
- Research needs may include statistical analysis

Ecological State

- Variables may include coral cover, fish species presence and fish species abundance
- Existing data may include coral reef monitoring data, and volunteer monitoring data
- Research needs may include statistical analysis and long term marine health monitoring

Role of Scientific Input in Decision Problem: Projecting Future Impacts of Management Options



Relationship	Current Knowledge	Research Needs
Relationship between population, economic output, land use, and water use & loadings	Increased population and output leads to increased water use & loadings	• Economic input-output models • Model relating population to water use and wastewater gen. • Scenario evaluation
Relationship between loadings & ambient WQ -N, P, Algal, DO, TSS, toxics	Excessive nutrients (N and P) lead to algal blooms & depressed O_2	• General ambient WQ model (USEPA, FL DEP) • Scenario evaluation
Relationships between ambient WQ, coral health and fish presence & abundance	Depressed O_2 can lead to a decrease in coral cover and an imbalance in fish number & diversity	• Linked WQ-ecological model • Coral health/fisheries model • Scenario evaluation
Relationship between coral, fish & ecosystem services (e.g., fisheries, recreation)	• Socioeconomic Monitoring Program (NOAA, etc) • *Recreation and Tourist Uses, Values, Attitudes and Perceptions* study (NOAA)	• Economic model to predict value of services from corals and fisheries (USEPA and FL DEP) • Scenario evaluation - Stakeholder valuation
Relationship between alternative management options and ecosystem services	No integrated model currently available	Development of integrated model

A3-Figure 11: Projecting Future Impacts of Management Options

Acronyms not previously defined:
O_2: Oxygen
USEPA: U.S. Environmental Protection Agency
FL DEP: Florida Department of Environmental Protection

This chart describes the role of scientific input in projecting the impacts of management options. This requires models to relate the different components of DPSIR, such as from Drivers to Pressures, Pressures to State, State to Impact, and Impact to Response.

- The first column includes the relationship of interest
- The second column includes the state of current scientific knowledge on the relationship
- The third column includes research needs for decision support

For example, if we take a narrow view of this problem and look closely at a limited piece: The DRIVER of *Population Growth* generates the PRESSURE of increased *Wastewater (volume)* and greater *Nitrogen (N) loadings*. A planning model is needed that predicts wastewater volumes given a population level. The *Wastewater (volume)* and greater *N loadings* generates a change in STATE of the ambient *N* and subsequently the ambient *algal* population. A WQ/ecological model (could be one model or separate models for each component) is needed that takes the *Wastewater (volume)* and *N loadings* and provides predictions of ambient *N* →

algal population → O2 → *coral cover*. The change (e.g., decrease) in the STATE of *coral cover* leads to an IMPACT on the snorkeling business (e.g., decrease). An econometric model is needed that relates coral cover to snorkeling business.

For this example, Management Options can attempt to control population growth (DRIVER) or the level of N treatment at the WWTP (PRESSURE). With costs of these management options compared to the benefits from the snorkel business.

The goal of the DSF is to help decision-makers look broadly across all stakeholder values, objectives, potential decision options, DRIVERS, PRESSURES,STATES, and IMPACTS to RESPOND with actions that meet the Objectives.

Appendix 4 – Sustainable Land and Resource Use Planning Criteria

The following essential attributes of natural systems are our current best estimate that will maintain ecosystem integrity and keep natural systems functioning. Because functioning natural systems are related to functioning social and economic systems, these criteria should be the basis for land-use decisions and evaluation.

System Component	No	Precondition of Intact Natural System
Productivity	1	Productive biomass of any land area is at near-natural levels.
	2	Native plants predominate the ecosystem
	3	Growing trees and plants bring nutrients from deep soils to form cellulose at the surface where they decompose.
	4	Native coastal mangroves, wetlands, sea grass beds, and coral reefs are intact.
	5	Water chemistry of sea-water is sufficient to maintain photosynthesizing plankton.
Biodiversity	6	Genetic diversity exists.
	7	Native and non-native species are isolated from each other.
	8	Fragments of truly native environments remain intact.
	9	Natural disturbance regimes exist or are simulated when they can not exist.
	10	Distribution of redundant species is maintained across multiple time and space scales.
	11	Habitats exist in configurations, sizes, and quality that meet physiological and behavioral needs of native populations and communities.
	12	Habitats are refreshed/renewed with clean water.
	13	Native spawning/birthing/hatching sites continue to exist in useful condition.
	14	Connectivity between spawning/birthing/hatching sites and maturation areas and return is open and accessible (including migration).
	15	Individual species and communities are widely dispersed beyond the range of any disturbance regime.
	16	Connectivity between habitats is redundant and grain is appropriate for native species.
	17	Unique environments remain intact.
Soils	18	Soil minerals are renewed.
	19	Adequate moisture exists to make nutrients soluble.
	20	Soil chemistry and ph sustains native soil bacteria, microorganisms, and plants.
	21	Organic natural wastes are abundant.
Water	22	Ground water recharges 〈 withdrawals.
	23	Surface water recharge 〈 all combined water uses.
	24	Wetlands exist to purify waters.
	25	Avenues for groundwater recharge are clean.
	26	Air and water must be clean enough for autotrophs to live.
	27	Water quantity and speed of surface flows meet historic cycles, durations, and intensities.
	28	Soil compaction/impermeability and soil cover do not increase runoff above near-natural levels.
	29	Trees/plants break the force of falling rain and loosen soil to allow absorption and slow runoff.
Air/Atmosphere	30	Sufficient forests exist to generate Hydroxyl radicals to process pollutant levels in the atmosphere.
	31	New deciduous forests and crops exist in higher latitudes and old forests exist to consume CO_2.
Energy	32	Forests exist in sufficient contiguous sizes to translate and moderate energy influx.

A4 Table 1 – Criteria for Sustainable Natural Systems

System Component	No	Precondition of Intact Social System
Social	33	A history and progression of how people faced problems is evident and transparent.
	34	Places that provoke spiritual feelings remain intact.
	35	Plant and animal taxonomy is documented.
	36	People are able to freely interact and share ideas, labor, and resources.
	37	Individuals have a voice in matters that affect them.
	38	Risks to human life/health are known.
	39	Human life is isolated from stochastic events.
	40	Institutions exist to serve collective society.
	41	Health risks are monitored and potential risks are made public.

A4 Table 2 – Criteria for Sustainable Social Systems

System Component	No	Precondition of Intact Economic System
Economic	42	Materials are efficiently used and reused as much as possible.
	43	Waste is attenuated by environmental processes.
	44	Resource use is linked with investment in resource renewal.[1]
	45	Qualitative community resources are improved.
	46	Net economic effects > costs incurred to natural systems.
	47	Net economic effects > costs incurred to social systems.
	48	Consumption of natural resources is counted as a cost.
	49	All costs are calculated before being incurred.
	50	Financial resources are sufficient to maintain community infrastructures, institutions, and services.

A4 Table 3 – Criteria for Sustainable Economic Systems

Appendix 5 – Glossary of Terms in the Ecosystem Services Tools Database

Tool Type	Description
Decision Support System	See right side, Figure 8
Process Based Model	Model that uses physical or chemical principles
Guidance	Synthesis of information to aid decision making
Economic Model	Model that focuses on the interaction between the environment, the humans, and our use of goods and services
Empirical Model	Model that use and test hypotheses through observation and experimentation
Social Networking	Tool that measures interactions among individuals or groups in decision making
Mapping Tool	Tool or application that builds maps from external information, such as remote sensing images
Database	An organized compilation of data
Maps	Portal for distribution of existing maps
Model Development Tool	Development environment for constructing models
Conceptual Modeling	Tool for building concept maps and models
Government Program	A government agency or program that produces outputs useful for ecosystem services decision support
Valuation	Tool or methodology for quantifying value for economic analysis and decision support
Landscape Model	Models which use landscape metrics for data reduction
Game	Role-playing tool
Probabilistic Model	Model which uses elements of probability theory
Workshop	Product that came from a workshop
Multi Media Model	Model that considers fate and transport among different environmental media (e.g., soil, surface water, air)
Presentation	Presentation that serves as a decision support tool
Search	Search engine

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